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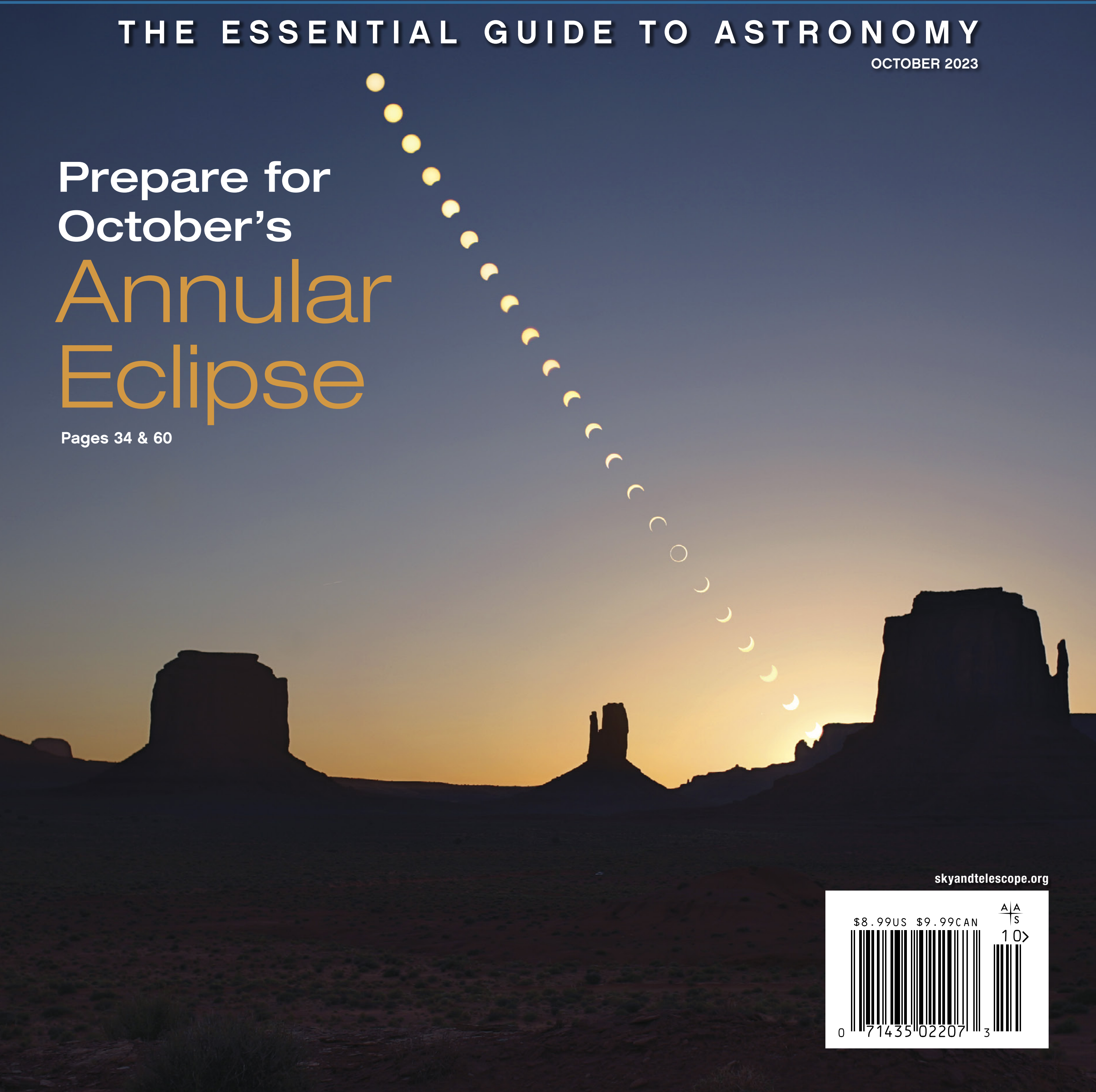
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

OCTOBER 2023



Prepare for October's Annular Eclipse

Pages 34 & 60

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October 2023 VOL. 146, NO. 4

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Annular eclipse over Monument Valley Navajo Tribal Park
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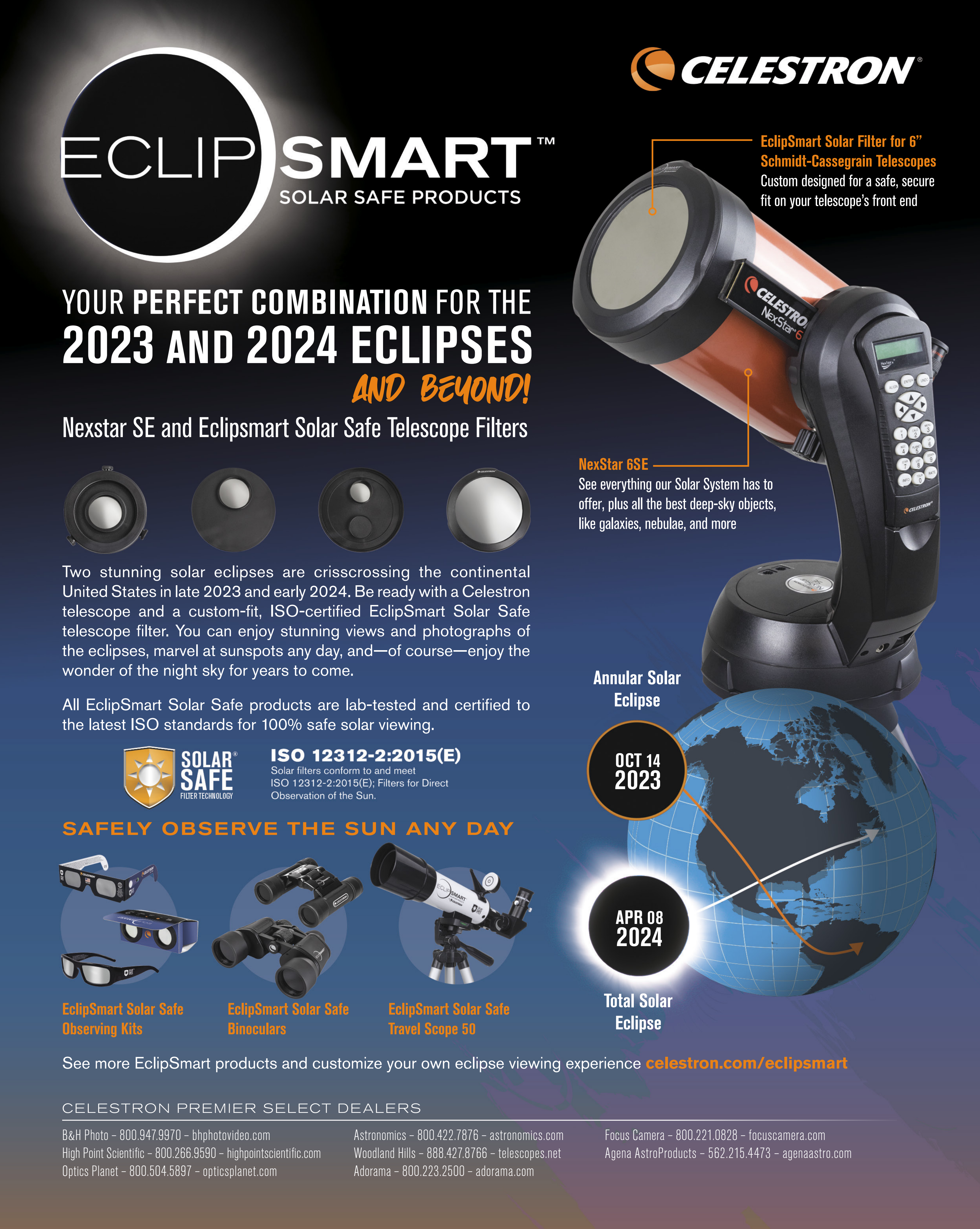

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Main Sequence

A SOLAR ECLIPSE TAKES VIEWERS on quite a ride. Whether it's annular or total, an eclipse of the Sun offers arguably the most exquisite progression of dramatic changes to celestial objects that we can observe from Earth with the naked eye (with proper protection, of course).

Have a look at Fred Espenak's striking composite of the 2005 annular eclipse on page 34. If you start in the upper left and work your way visually left to right and down each row to the lower right, you get a palpable sense of this exacting succession. As you eyeball each stage, vague references pop into mind: a chipped bowl, a bitten cracker, the Apple logo, a boomerang, and finally a golden wedding ring before "reversing" back to the chipped bowl.

Whatever allusions pop into *your* mind, what stands out most prominently for all of us in that series is the series itself. The same is true of Rick Fienberg's arresting parade of images of the 2017 total eclipse on page 84. Given that witnessing the full run of any eclipse lasts several hours, taking in an entire eclipse at a glance is eminently satisfying. For another creative way to capture the whole chain of events in a single image, see Tunç Tezel's breathtaking composite of last April's hybrid eclipse and his accompanying feature on page 60. (See also Tezel's sublime cover shot.)

▲ Stately procession: multiple stages of the 2005 annular eclipse

FRED ESPENAK

The splendid advance of an eclipse extends well beyond any one photographer's location, of course. As the map on page 35 shows, the Moon's shadow during this month's annular will race overland from Oregon right down through Brazil. Could an eclipse possibly cover a greater extent of the Americas than October 14th's annular will?

Another sequence that comes to mind is that of eclipses over the coming decades. As Rick Fienberg notes in his Focal Point, solar eclipses aren't particularly rare; they happen somewhere on the planet every year or two. But take heed: After April's totality and October's annularity, the next solar eclipses to cross a significant portion of the United States will not happen until 2045 and 2048, respectively.

So, if you're an eclipsophile based in the U.S., you won't want to miss these two imminent shadowings. The previews by Fred Espenak and Jay Anderson on page 34 of this issue (for the annular) and on page 26 of last April's issue (for the total) will set you on your way.

Peter

Editor in Chief

Editorial Correspondence
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Jupiter Deflection Project — Call for Observations

During the night of October 27–28, 2023, one of Einstein's wishes might finally be fulfilled. Jupiter will pass by three bright stars (SAO 93015, SAO 93016, and SAO 93020), oriented such that measuring Jupiter's gravitational effect on the positions of one of the stars is possible! A similar deflection measurement of stars near the Sun during a total eclipse in 1919 made Einstein famous, but earlier he had proposed using Jupiter instead. This October, the deflection of SAO 93016 is only about 0.01″ — this is a challenging observation, which will require extraordinary seeing. However, the very rare linear alignment of the other two stars makes the measurement possible.

Amateur telescopes and cameras are perfectly suited to capture the images necessary for this experiment. If you're interested, you'll need a 5- to 8-inch telescope with a camera plate scale around 0.5 arcseconds per pixel. Be prepared to perform some preliminary preparations, such as testing your equipment on target stars ahead of time and taking calibration images the previous or following night. The Western Hemisphere is well placed for these observations, but in the U.S. the ideal locations are in the south, from California to Florida. As cloudy weather can occur anywhere, the call is out for observers everywhere the event is visible. For more information, go to **https://is.gd/JupiterDeflection**.

Don Bruns • San Diego, California

▲ Amateur equipment — such as this 8-inch (200-mm) Ritchey-Chrétien and 5-inch (127-mm) refractor with ASI1600MM Pro and ASI183MM Pro cameras mounted on a Paramount MYT equatorial mount — is perfect for the Jupiter deflection experiment.

DON BRUNS

Small-Body Spectrum

In "Active Asteroids" (*S&T:* June 2023, p. 12), Henry Hsieh discusses asteroids that show comet-like activity. He then indicates that this means that all small bodies are part of a single family of objects with variations. Another way of looking at this is to consider these small bodies to be on a spectrum. This is not surprising as nature tends to favor spectrums over strict categories.

James W. Scott
Vernon, New Jersey

Monica Young replies: *You make an excellent point, and indeed this is a pattern we see time and again in astronomy: that what were once considered distinct classes turn out to be a part of a spectrum. In this case, it was surprising because we thought there was a mechanism that would keep the classes distinct. Comets still had ice that hadn't sublimated yet and therefore could appear "active," whereas asteroids should have lost that ice long ago. In finding "active asteroids," we've learned a lot about what can drive activity!*

Finding Your Way

Jerry Oltion's excellent article "Make a Plate-Solving Finder" (*S&T:* May 2023, p. 70) also contains a hint at an easy upgrade for telescopes without accurate position readout. He writes: "You need a computer that's capable of running the astrometry.net software." [and] "You need a camera capable of taking a reasonably fast photo of the night sky." If they're using a computer-connected camera on a telescope, then they already have all the hardware required and need only install the *astrometry.net* software, or use the web interface, to find exactly where the telescope is pointing in seconds. This is a great aid in accurately pinpointing faint targets.

Art Whipple
Tracys Landing, Maryland

Chi Cygni

Following the suggestion in Bob King's "Keeping an Eye on Chi" (*S&T:* May 2023, p. 49), I have been monitoring variable star Chi Cygni near its predicted maximum. On May 18th between 3:40 and 3:45 a.m. EDT, I estimated the star's brightness at 5.1 magnitude. While doing so, three low-Earth-orbiting satellites whizzed through the field of my 7×50 binoculars. They were about 7th magnitude. Seeing so many of them during such a brief time made me realize how vulnerable Earth-based imaging efforts must be due to their presence. And with thousands more Starlink satellites launching in coming months, the night sky will become even more polluted by orbiting devices!

Richard Taibi
Severn, Maryland

Above and Beyond

My wife and I were on a cruise off Exmouth, Australia, for the solar eclipse on April 20, 2023. Representatives of *Sky & Telescope* were present. We want to thank them and *S&T* for how generously these people shared their astronomical knowledge with all of us, even if we were not on *S&T*'s official tour. Kelly Beatty was amazing! He gave guided tours of the night sky from the stern of the ship, talked with any of us that approached him on the cruise, and ensured that the captain of the *P&O Pacific Explorer* was in the optimal position for the eclipse. He was so selfless that he did not even get to see the eclipse himself; instead he made sure all of us umbraphiles were ready for the spectacular 58 seconds of totality.

Please extend our sincere thanks!

Kevin and Mary Gustafson
Chanhassen, Minnesota

Astronomy for Retirees

I was very interested in Robert Richard's "An Observatory for Seniors" (*S&T:* July 2023, p. 84). My wife and I retired to Arizona a few years ago. I started observing with a telescope but ran into a few issues. I had similar ideas about remote viewing with an internet-based arrangement. Now,

after reading how he did it in his community, I have begun to pencil out what that would take.

Edward Daugherty
Goodyear, Arizona

"An Observatory for Seniors" sums up my experience to a T. I also moved to a continuing-care facility (in Matthews, North Carolina), and I have been experiencing the same issues Dr. Richard went through. Setting up and taking down my equipment as well as moving it to a site in the complex can be off-putting to say the least.

But our facility has been supportive of my hobby. Recently, they put a nature trail in the back section of the property and constructed an observing deck. Their first plan for this deck was an observation platform to watch the ducks and geese on the pond, but they're planning to install electricity in the platform for my use. We have also discussed having Wi-Fi available to project images for those not mobile enough to observe through a telescope.

Benton Kesler
Matthews, North Carolina

It Takes Two

When I wrote "It Takes a Village" (*S&T:* Oct. 2020, p. 84), the Goldendale Sky Village membership stood at 21. Now our 30-acre community has 59 members, and the infrastructure is complete.

In that article, I wrote: "We would also encourage the founding of other sky villages around the U.S. . . ." We have been successful in this endeavor as well. Our 92-acre sister village, Chiricahua Sky Village, is arising under dark skies in southeastern Arizona and currently has 44 members from six states. Both villages are continuing to grow — something I attribute to the innovative combination of private ownership and relatively small lots positioned close to each other. This has led to a unique observing environment that looks and feels like a permanent star party.

Christopher Smythies
Founder and General Manager
Goldendale and Chiricahua Sky Villages
Medina, Washington

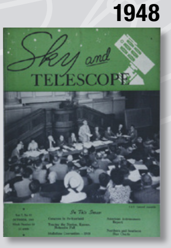
FOR THE RECORD

- In "Visiting Ophiuchus" (*S&T:* June 2023, p. 45), Aesculapius carries a rod with a single snake wrapped around it, known as the Staff of Aesculapius. The "caduceus" is a staff entwined with two snakes belonging to Hermes, the Greek messenger god. Both staffs serve as a symbol for the medical profession today.
- On page 27 in the August 2023 issue, Williamina Fleming discovered Z Centauri in December 1895 on a photographic plate taken in July of that year.

SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

1948



1973

1998

◖ October 1948

Number Crunching "Extremely rapid solution of some of the complex and laborious numerical problems of astronomy may soon be available by means of EDVAC, the Electronic Discrete VAriable Computer [at the University of Pennsylvania]. The new calculator is comparatively small in size, some seven feet high and taking up 140 square feet of floor space. It uses 3,300 commercially available vacuum tubes . . .

"[To calculate] the orbit of an asteroid or newly discovered comet [will take] only about 75 seconds!"

Fuzzy Interloper "[A new] comet was found on August 26th, by Dr. Joseph Ashbrook at Lowell Observatory, of the 12th magnitude, in the constellation Aquarius. Comet Ashbrook will not increase much in brightness, for its nearest approach to the sun, late in April, 1949, is about 218 million miles."

Cyril V. Jackson in South Africa also discovered this comet, which is now called 47P/Ashbrook-Jackson. Joseph Ashbrook joined the staff of this magazine in 1953 and was Editor from 1964 to 1980.

◖ October 1973

Optical Pulsars "Most astrophysicists believe that the pulsars are rotating neutron stars, and that the formation of a neutron star is accompanied by a supernova explosion. . . . Hence, the known locations of supernovae are likely sites at which to detect pulsars.

"This is the argument of C. Papaliolios and P. Horowitz, who . . . used the Smithsonian Astrophysical Observatory's 60-inch reflector in Arizona and Harvard Observatory's 61-inch in Massachusetts to search for optical pulsars at the positions of 31 extragalactic supernovae. . . . Nevertheless, no optical pulsar could be detected at any of the 31 sites, even though the technique should have shown objects as faint as magnitude 20 or 21."

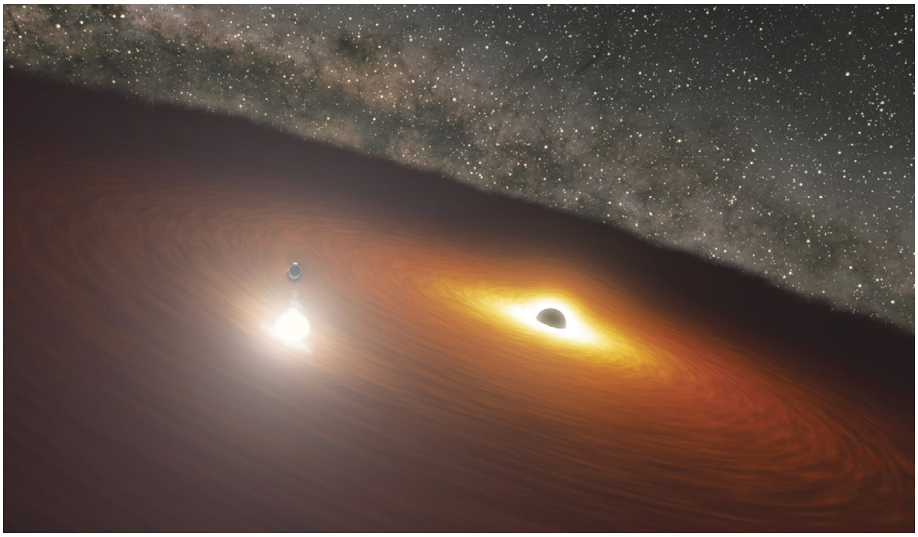
Even today, just a tiny handful of pulsars have been observed optically, compared to 3,000 found with radio telescopes.

◖ October 1998

June Meteors "If you were out skywatching during the final weekend in June, you may have noticed more bright meteors than usual. . . . Japanese observers made the first official report on a June 27th IAU *Circular.* There, Isao Sato (National Astronomical Observatory, Tokyo) passed on a description of meteors being seen at a rate of 40 to 50 per hour through heavy cloud cover on the previous night. . . .

"This isn't the first time meteors have been seen streaming from Boötes. Jürgen Rendtel (International Meteor Organization) notes that similar showers were well observed in 1916, 1927, and possibly 1921."

The June Boötids have joined the ranks of known meteor showers, although their peak hourly rate varies greatly from year to year.



BLACK HOLES

Signal from OJ 287's Second Black Hole

ASTRONOMERS HAVE LONG suspected that the distant galaxy OJ 287 harbors not one but two supermassive black holes in its core — one with the mass of a whopping 18 billion Suns, the other a comparatively diminutive, 150-million-solar-mass companion. At the 242nd meeting of the American Astronomical Society, Mauri Valtonen (University of Turku, Finland) announced that his team detected a new set of flares from the second black hole.

Astronomers have been recording OJ 287's light, which travels some 3½ billion light-years to Earth, since 1888. In the 1980s, Aimo Sillanpää (Tuorla Observatory, Finland) and colleagues used the long archive to show a roughly 12-year cycle in outbursts from OJ 287, which the astronomers attributed to a pair of orbiting black holes.

Further investigation revealed that the outbursts seen every 12 years are actually sets of twin, weeks-long flares. Sillanpää, Valtonen, and colleagues interpreted these flares as arising when the secondary black hole plunges into and exits the gaseous accretion disk surrounding the primary black hole.

Using models of the black hole pair's interactions, astronomers were able to predict when the next set of outbursts should occur. In 2021 and 2022, the team unleashed a campaign across multiple wavelengths to observe the system. The astronomers caught the activity from the secondary's plunge into the accretion disk within days of the predicted time. But the campaign also caught two unexpected features.

▲ This illustration shows the putative black hole binary in OJ 287. See the animation at **https://is.gd/OJ287video**.

To the team's surprise, Staszek Zola (Jagiellonian University, Poland) caught a brief (day-long), highly energetic spurt of light in an *R*-band filter. Analysis indicates that this brief flare would have occurred when the secondary black hole swallowed a massive dose of new gas during its plunge through the primary's accretion disk.

The second surprise came when the Fermi Gamma-ray Space Telescope detected high-energy radiation. The team attributes this to the secondary black hole's jet interacting with gas in the primary's disk. A trawl through archival data turned up a similar gamma-ray flare coinciding with a predicted outburst in 2013.

Valtonen argues that the newest set of flares points at multiple stages of interaction as the secondary black hole passes through the primary's disk — including, for the first time, emission that's coming from the secondary itself.
■ DIANA HANNIKAINEN

STARS

How Soon Will Betelgeuse Blow?

MANY ASTRONOMERS THINK Betelgeuse, the red supergiant star marking Orion's shoulder, will go supernova soon — that is, within the next 10,000 to 100,000 years. In a new study posted June 1st on the arXiv astronomy preprint server, Hideyuki Saio (Tohoku University, Japan) and colleagues claim that star might be closer to exploding than we thought. But others disagree.

Betelgeuse "breathes" in and out, with overlapping overtones, resulting in regular brightness changes over periods of 2,200 days, 420 days, 230 days, and 185 days. Usually, astronomers treat the 420-day up-and-down as the primary in-and-out pulsation, with the shorter cycles as overtones. The 2,200-day (or 6-year) period is dubbed a *long secondary period*, a feature of unknown origin found in

SUPERNOVAE

We Could Soon "Hear" Gravitational Waves from Dying Stars

A NEW POSSIBLE SOURCE of gravitational waves is the cocoon of hot, dense gas that forms within a massive, dying star. This source is within reach of the recently begun observing run of the Laser Interferometer Gravitational-Wave Observatory (LIGO).

Hefty stars with 20 to 40 times the Sun's mass die in particularly spectacular fashion. First the center collapses into a black hole, which in turn powers two opposite jets that drill their way out of the star. As the jets ram their way through the outer stellar layers, they amass a sheath of hot, dense star-stuff.

Ore Gottlieb (Northwestern University) and colleagues only recently realized this accelerating cocoon of gas could emit gravita-

NASA / JPL-CALTECH

one-third of supergiants. If the 420-day period is primary, then Betelgeuse would have the diameter of 800 to 900 Suns.

Saio and colleagues, however, propose that the 2,200-day cycle is primary, in which case the star would span 1,200 Suns. To show this, Saio's team employs computer simulations to watch stars evolve from birth to old age; then they calculate the pulsations that occur at each stage. They find that radial pulsations during the late stages of carbon-burning would explain all four periods.

"After carbon is exhausted in the core, a core-collapse leading to a supernova explosion is expected in a few tens [of] years," the researchers write. It's hard to tell when the carbon will run out, Saio acknowledges; he puts it at less than a few hundred years.

Other researchers expressed qualms about the new calculations. László

◀ This artist's impression shows the supergiant star Betelgeuse.

Molnár (Konkoly Observatory, Hungary) and colleagues argue in the June *Research Notes of the AAS* that the estimated size doesn't match interferometric measurements.

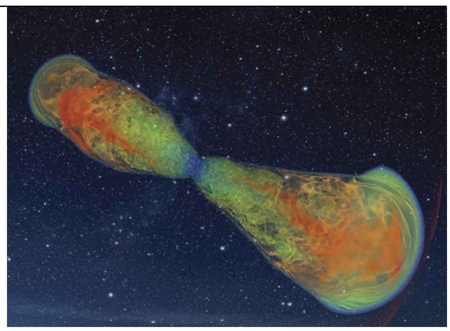
Another mismatch comes from spectroscopic measurements, which show the star's surface is expanding and contracting at 1.5 km/sec (3,300 mph). At this rate, the star would change its total diameter by 180 times the Sun's size every cycle, which would in turn affect the overtones. "These changes would be expected to repeat systematically every 2,200-day cycle," says Morgan MacLeod (Center for Astrophysics, Harvard & Smithsonian), a theorist who studies pulsating stars. "I don't think we see evidence for that in Betelgeuse's long-term light curve."

■ **MONICA YOUNG**

tional waves. "To be honest, I didn't look for cocoons," he says. "It was more or less by chance that I started to try to understand their gravitational-wave emission."

It wasn't immediately obvious that these gravitational waves would have the right pitch and volume for LIGO to "hear" them. To find out, Gottlieb's team ran computer simulations that followed the jets — and the cocoons around them — all the way from their launch near the black hole to where they punch through the stellar surface and escape to space. They then calculated the resulting gravitational-wave signal, which Gottlieb presented at the 242nd meeting of the American Astronomical Society.

Unlike the chirps of inspiraling black hole pairs, the signal from an emerging jet-cocoon sounds like an eerie howl of wind. Crucially, that signal is both loud enough and at the right frequencies for LIGO to detect during its fourth observing run, which started on May 24th. This new type of gravitational-wave



▲ As the jet's cocoon pierces the exploding star's outer layers, it emits gravitational waves. The color in this simulation frame indicates the strength of the gravitational-wave signal.

signal could offer astronomers insights into how stars' cores collapse.

Supernovae of massive stars are rare, though. "We expect something like a 1% chance of cocoon gravitational waves in the fourth observing run; in the fifth, it should increase to about 10%," Gottlieb predicts. Most likely, he adds, we'll have to wait for third-generation detectors.

Still, you never know what you might find by chance.

■ **MONICA YOUNG**

BLACK HOLES

Even Lonely Black Holes Need to Eat

LESS THAN A FIFTH of all galaxies reside within the most empty regions of space, *cosmic voids*. These isolated galaxies offer a window on uninterrupted galaxy growth and evolution.

Fewer collisions in voids mean less fresh gas for fueling galaxies' star formation — and for feeding their central supermassive black holes. Yet in a new study, Anish Aradhey, who just graduated from Harrisonburg High School, and astrophysics professor Anca Constantin (James Madison University), show that these black holes feed even in isolation.

Aradhey, who presented at the 242nd meeting of the American Astronomical Society, started with 290,000 galaxies flagged in the Sloan Digital Sky Survey. He looked for those galaxies in series of images from the Wide-field Infrared Survey Explorer. Those flickering at infrared wavelengths host feeding supermassive black holes. Aradhey mapped out more than 20,000 such flickering galaxies, or *active galactic nuclei* (AGN), to determine if they were in a cosmic void.

It turns out that voids are actually more likely to host AGN — but only in smaller galaxies. Milky Way–size galaxies and larger instead tend to be more active in crowded regions.

While the result confirms that active galaxies' life cycles slow down in voids, it contradicts previous ideas about the role of galaxy mergers in evolution. While mergers and other interactions can encourage gas flow into a galaxy's central black hole, they're apparently not necessary.

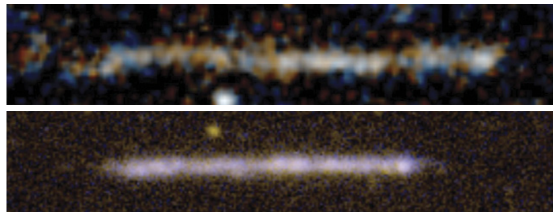
Ryan Hickox (Dartmouth College), who wasn't involved in the study, speculates that lack of competition may actually be beneficial. "Interaction with other galaxies would strip or disrupt their gas, and so there is more fuel to power accretion in those systems," he suggests.

■ **MONICA YOUNG**

BETELGEUSE ILLUSTRATION: ESO / L. CALÇADA; JET/COCOON
SIMULATION: ORE GOTTLIEB / CIERA / NORTHWESTERN UNIVERSITY

BLACK HOLES

“Rogue Black Hole” Might Be Something Much Simpler



▲ A linear feature discovered in a Hubble Space Telescope image (top) rotates in a manner similar to an edge-on galaxy, an example of which (IC 5249) is shown at bottom. Both images are taken at the same scale and at ultraviolet wavelengths.

AN UNUSUAL STREAK of stars thought to have formed in the wake of a wandering supermassive black hole (*S&T:* June 2023, p. 10) might turn out to be a spiral galaxy seen edge-on. Astronomers propose the simpler alternative in a study to appear in *Astronomy & Astrophysics Letters*.

Earlier this year, Pieter van Dokkum (Yale University) and colleagues spotted a trail of stars longer than the Milky Way is wide. The trail appears to emerge from a distant galaxy in a Hubble image. The team proposed that a collision between galaxies had ejected the supermassive black hole at the core of one of them. As it plowed through sparse gas around the galaxy, it triggered star formation in its wake.

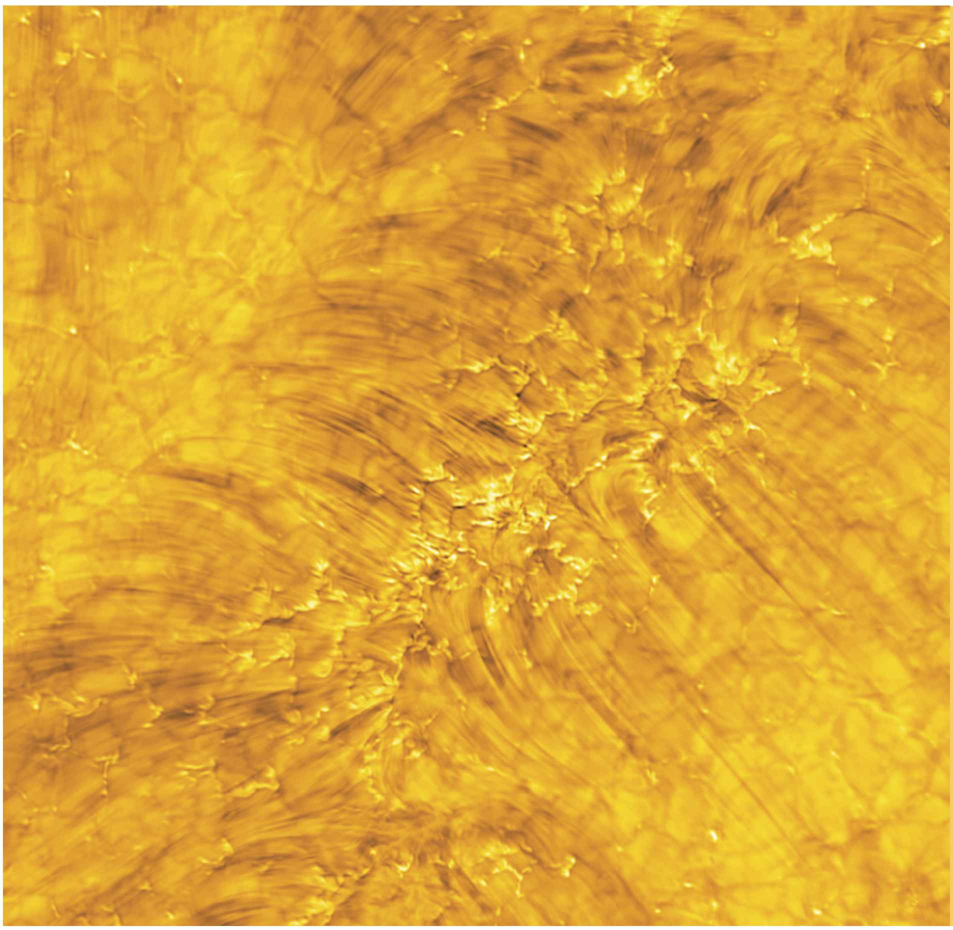
However, Jorge Sánchez Almeida (Institute of Astrophysics of the Canaries, Spain) says circumstances have to be just right for black holes to reveal their presence in this way. He led the new study after he and his colleagues examined a plot of the trail stars’ velocities and positions. They realized that the graph looked like the rotating disk of an ordinary spiral galaxy. According to Sánchez Almeida, a trail of stars forming in the wake of a supermassive black hole shouldn’t rotate in this way.

“From our point of view, this is a killer of the original interpretation,” says Sánchez Almeida. “We still expect supermassive black holes to go for a stroll in galaxy halos, but this is simply not a good example.”

However, in the May *Research Notes of the AAS*, van Dokkum contradicts this idea, noting a bridge of emission between the star stream and the galaxy next to it. The bridge, detected in a new image from the Very Large Telescope in Chile, appears as a few pixels of faint emission. Both the trail of stars and the nearby galaxy are at the same distance, and the bridge between them “basically rules out that the two objects are independent,” van Dokkum says.

Forthcoming observations from the Hubble and James Webb Space Telescopes should help differentiate whether the trail of stars is an edge-on spiral or indicative of a runaway black hole.

■ **JAVIER BARBUZANO**



New Images of the Sun

The Daniel K. Inouye Solar Telescope, part of Haleakalā Observatory on Maui, Hawai‘i, has returned a stunning set of close-up images of the Sun, taken with the Visible Broadband Imager. During the first year of commissioning observations, completed in February, astronomers tested and calibrated instruments while also conducting science. The Inouye telescope is operating with four of its five first-generation instruments; the fifth should be integrated next year. The image at left captures details in the visible surface of the Sun, known as the *photosphere*, as well as the hotter *chromosphere* just above it. Convection cells in the boiling plasma can be seen on the surface as *granules*. Darker strings called *fibrils* come from magnetic fields that accumulate like bunches of uncooked spaghetti in the chromosphere. View all eight images at **https://is.gd/DKIST**.

■ **MONICA YOUNG**

STELLAR STREAM AND EDGE-ON GALAXY: HST; SUN: NSF / AURA / NSO; IMAGE PROCESSING: FRIEDRICH WÖGER (NSO), CATHERINE FISCHER (NSO); SCIENCE CREDIT: PUBLIC DDT DATA

OBITUARY

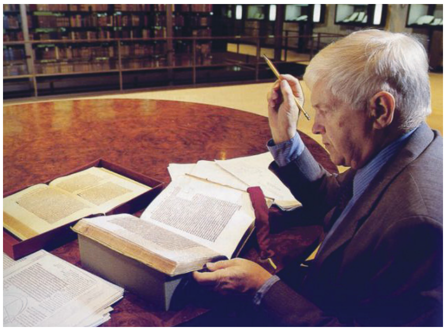
Owen Jay Gingerich, 1930–2023

OWEN JAY GINGERICH, well-known astronomy historian and long-time contributor to *Sky & Telescope*, died on May 28, 2023. Owen held joint appointments at Harvard University (Professor of Astronomy and of History of Science) and at the Smithsonian Astrophysical Observatory (Astrophysicist), and he researched, wrote, and lectured well into his retirement years.

Born in 1930 to Mennonite parents, Owen maintained his faith throughout his life. Dark, starry nights sparked his imagination as a child. He paid the lifetime membership fee for the American Association of Variable Star Observers while he was still in high school. After graduating from Goshen College in Indiana, Owen briefly worked part-time for *Sky & Telescope* while pursuing a Master's degree at Harvard; his *S&T* contributions would continue for decades. In 1955, he and his wife, Miriam, traveled to Lebanon, where he taught astronomy at American University of Beirut. Their first two children were born in Beirut. In 1958, the family returned to Cambridge, where Owen taught astronomy at Wellesley College while completing his PhD at Harvard under advisors Charles Whitney and Cecilia Payne-Gaposchkin.

Around this time, Owen began teaching an astronomy course for non-science majors, one he would coteach with David Latham for 35 years. It became one of Harvard's most popular courses. Owen also took over editing the Harvard Announcement Cards and directed the Central Bureau for Astronomical Telegrams from 1965 to 1968.

Early in his career, Owen became intrigued by how the works of Copernicus, Galileo, and Kepler helped transform ancient astronomy into a science based on celestial mechanics and math. Owen collected and published findings on scores of early-modern printed astronomy tracts. In particular, he spent decades examining every copy of Copernicus's landmark 1543 treatise,



De Revolutionibus, analyzing contemporary astronomers' interpretation of the book via their handwritten annotations. He details the copies in his 2002 *An Annotated Census of Copernicus' De Revolutionibus*. The escapades he had along the way became a story of their own in 2004, published in *The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus*.

In 2006, Owen chaired the International Astronomical Union (IAU) Planet Definition Committee. The committee proposed including larger trans-Neptunian objects (TNOs) as well as the asteroid 1 Ceres with Pluto as planets. However, the IAU General Assembly instead adopted Pluto, Ceres, and other large TNOs as "dwarf planets." The solar system's largest worlds were simply called "planets" — even though Owen had urged the use of an adjective before "planet." Owen documented these events in the November 2006 *S&T*.

Between 1950 and 2006, Owen wrote more than 100 *S&T* pieces, including Laboratory Exercises in Astronomy, book reviews, observing reports, and feature articles. He also took on a five-year stint writing the Astronomical Scrapbook column.

In recognition of Owen's accomplishments in the study of the history of astronomy, the minor planet 2658 Gingerich was named for him. Those of us fortunate enough to spend time with Owen were impressed with his encyclopedic knowledge. It's impossible to replace his expertise and insight, but we are fortunate to have so much of it in his many publications.

■ DANIEL W. E. GREEN

Read the full obituary at https://is.gd/OwenGingerich.

CENTER FOR ASTROPHYSICS, HARVARD & SMITHSONIAN

IN BRIEF

Solar Wind Source Found

The origin of the *solar wind*, made of charged particles and magnetic fields, remains unknown. Stuart Bale (University of California, Berkeley) and colleagues used data from the NASA Parker Solar Probe's 10th perihelion in November 2021 to examine the *fast* solar wind, which emerges along magnetic field lines open to interplanetary space. Two competing mechanisms might launch this wind: *Alfvén waves* carried by particles and their associated magnetic fields, or *magnetic reconnection*, the snap of field lines. Flying through the solar wind, Parker measured particle energies, their outward speed, and the magnetic field; the Solar Dynamics Observatory provided field measurements from a different vantage point. The team saw that short, jet-like bursts of solar wind buffeted Parker during its close encounter. With the help of computer simulations, the team reports in the June 8th *Nature* that reconnection in between large convection cells known as *supergranules* likely drives these bursts. However, the researchers also note that Alfvén waves may still be involved, albeit indirectly.

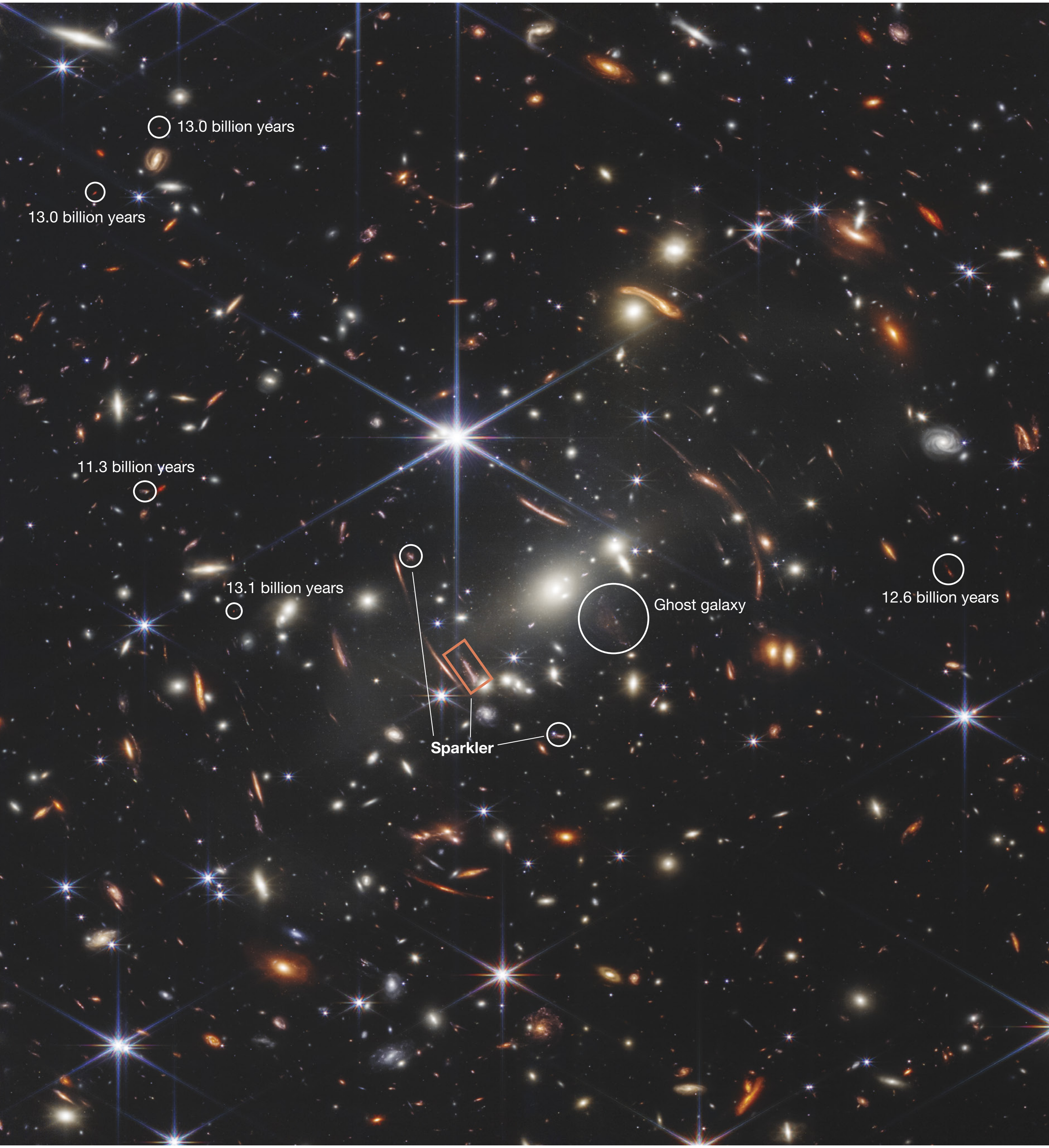
■ KIT GILCHRIST

Read the full story at https://is.gd/fastsolarwind.

Phosphates on Enceladus

Researchers led by Frank Postberg (Free University of Berlin) announced the first detection of phosphorus in an extraterrestrial ocean in the June 15th *Nature*. The team examined data collected by the Cosmic Dust Analyzer (CDA) aboard NASA's Cassini orbiter as it passed through Saturn's E ring. Some of the E ring's particles come from Enceladus's south polar geysers, which in turn come from the moon's subcrustal ocean. These tiny, frozen droplets therefore contain the salts dissolved in Enceladus's ocean water. The CDA separated ions in these particles by atomic mass. Postberg's team examined 345 such particles in the CDA data archives, nine of which contained significant numbers of ions with masses of 125, 165, and 187 atomic units. These ions correspond to the mineral sodium phosphate, as confirmed via lab experiments. The detection means that the availability of phosphorus is unlikely to be a limiting factor for life within Enceladus or other ocean worlds.

■ EMILY LAKDAWALLA


13.0 billion years
13.0 billion years
11.3 billion years
13.1 billion years
Ghost galaxy
12.6 billion years
Sparkler

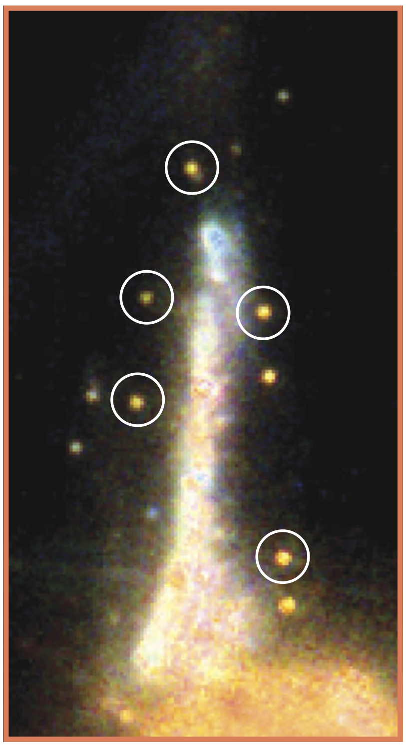
JWST Reveals the Early Universe

The first observations from astronomers' triumphant new telescope are giving us an unprecedented look at galaxies from the first billion years of cosmic history.

What were astronomers expecting to see when we used the James Webb Space Telescope (JWST) to look at the universe's first few billion years? Previous observations by the Hubble Space Telescope had revealed a beautiful diversity of galaxies that changed over cosmic time. Studies showed that billions of years ago, galaxies were young, active, and disordered — yet to settle into the majestic spiral disks and elliptical shapes we see around us today. The farther away we searched and the further back in time we looked, the fewer galaxies we found and the less detail we saw, until all the galaxies became just tiny, pale, infrared dots. Unexpectedly, their numbers dropped off a cliff 500 million years after the Big Bang, at the limits of what Hubble can see. Were there actually so few galaxies that early in the history of our universe, or were they just very hard to find?

Stunning pictures from JWST have reassured us that the early universe was ripe with galaxies. Astronomers have now confirmed distances to galaxies observed as early as 320 million years after the Big Bang. Some studies have found "too many" galaxies at early times (*S&T:* May 2023, p. 9), potentially transforming our understanding of the universe. Others reveal galaxies bristling with stars of different ages. And amidst all the chaos in the early universe, we now find that some galaxies managed to settle into peaceful oases and even graceful disks.

In this article, we bring together some of the exciting new JWST discoveries, telling a story of a much busier and more developed early universe than previously imagined. We also discuss whether these new findings have broken our understanding of the universe or merely reshaped it.



◀▶ **GALACTIC KALEIDOSCOPE** The galaxy cluster SMACS 0723 provides a natural lens and magnifying glass to reveal galaxies far behind it. One of these is the Sparkler, which is studded with star clusters *(right, with potential globular clusters circled)*. The Sparkler appears three times in the cluster image; we've boxed the inset one. Also visible are even earlier galaxies, including three from more than 13 billion years ago. These look similar to compact star-forming galaxies called Green Peas in today's universe (see page 20).

LENSING CLUSTER: NASA / ESA / CSA / STSCI; SPARKLER: L. MOWLA ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2022

A Cosmic Spring?

We were blown away by the first images released in July 2022. JWST's large mirror and superb instruments revealed distant galaxies unlike any we had seen before. The details were enhanced by one of nature's cosmic telescopes: a massive cluster of galaxies named SMACS 0723. This cluster lies a few billion light-years away from us and acts as a gravitational lens, bending spacetime and magnifying the images of even more distant galaxies beyond it. Using galaxy clusters as lenses increases the reach of our most powerful telescopes.

One ghostly galaxy features a faint sheet of stars just barely visible, punctuated by bright, small star clusters. Another, dubbed the Sparkler, is elongated and also speckled with small star clusters. We presumed the star clusters were tiny buds of new growth that ushered in a "cosmic spring" some 9 billion years ago. We were so inspired by these discoveries that we even named our science team Cosmic Spring.

But our first guess was wrong: These were not actually tiny buds of new star formation. When astronomers analyzed the images, they determined these star clusters were already billions of years old, similar to globular clusters in our Milky Way, and born at a similar time, 13 billion years ago. While most galaxies in the early universe are young and still actively forming, JWST revealed that at least some of them already have very old clusters of stars that formed just a billion years after the Big Bang.

After the spectacular images of SMACS 0723, our team turned JWST's gaze to another galaxy cluster, WHL0137, and the most strongly magnified galaxy known in the universe's first billion years: the Sunrise Arc. At such a great distance, most galaxies appear as faint infrared smudges. However, thanks to the serendipitously perfect placement of the galaxy behind the cluster WHL0137, the Sunrise Arc is gravitationally lensed and magnified by a factor of hundreds, which reveals the smallest details visible anywhere in the universe's first billion years, including individual star clusters.

Based on our data and analysis, we found that some of these clusters are young and actively forming stars, as we expected in the early universe, but others are decidedly old and well-established, with ages of 30 million years or more. We determined that these old star clusters are gravitationally bound, meaning that they are likely to persist forever: Simulations show that once stars become drawn together in a tight swarm, almost nothing can disrupt them.

Without gravitational lensing, the Sunrise Arc might have seemed unremarkable, because the light from both the young and old stars would have blurred together and led to measurements of stellar ages somewhere in between. Instead, the old star clusters in the Sunrise Arc and the Sparkler give us clues to the history of the globular clusters in our Milky Way today (*S&T:* July 2021, p. 14). The surprising diversity of ages shows us how our early observations and ideas can change with a deeper, more focused look.

Surprising Disks

Over the past 13 billion years, the universe has expanded in size by a factor of eight, stretching and *redshifting* the light to wavelengths eight times longer than the photons were emitted with. Sun-like stars are invisible to Hubble at that distance, with their mostly yellow light redshifted to infrared wavelengths beyond Hubble's vision. That is why JWST was designed to see in the infrared. Within distant galaxies, Hubble can only see the young, hot stars that burned bright in ultraviolet light. JWST's infrared instruments reveal a full stellar census of each distant galaxy, including stars of all colors and ages. This new technological capability is what enables us to see these older star clusters in the early universe for the first time.

With Hubble, most distant galaxies appeared clumpy, with young star clusters actively forming new stars. That remains true for most galaxies we see, but JWST has revealed that some distant galaxies also have massive stellar disks that were previously invisible to Hubble. Rather than finding all early galaxies are patchy and unsettled, JWST has shown that some galaxies may have formed disks 13 billion years ago, much earlier than anticipated.

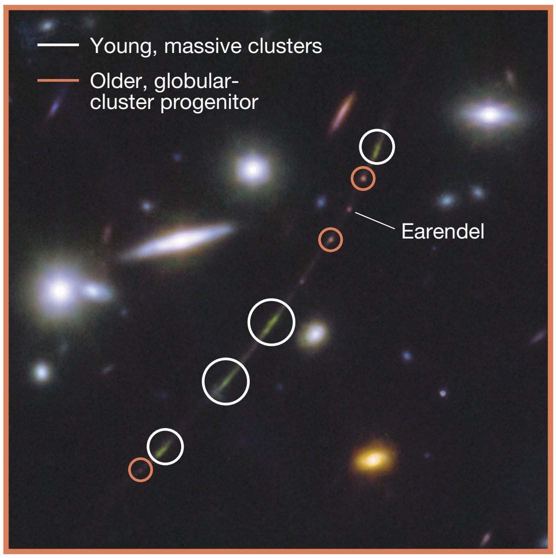
Our own Milky Way is more than 13 billion years old. Could it have had its disky shape for most of that time? Recent work using the Gaia space telescope suggests yes, our galaxy's disk first formed about 13 billion years ago (*S&T:* Aug. 2023, p. 34). Astronomers have wondered whether that makes the Milky Way unusual. But JWST's snapshots of distant galaxies suggest that such rapid development is more common than we expected. We'll soon learn more: Observers have now identified more than 700 galaxies that appear to shine at us from the universe's first 600 million years, and the analysis of those galaxies' shapes has only just begun.

Oases Calmed by Black Holes

By revealing the older stars in distant galaxies, JWST has also found entire galaxies that are surprisingly old and dormant, having not formed new stars for tens or even hundreds of millions of years. The early universe is small and densely packed with gas ready to compress and form stars, yet JWST is revealing that some galaxies are taking a peaceful break from star formation as early as 700 million years after the Big Bang. How have these galaxies found temporary calm during such tumultuous times?

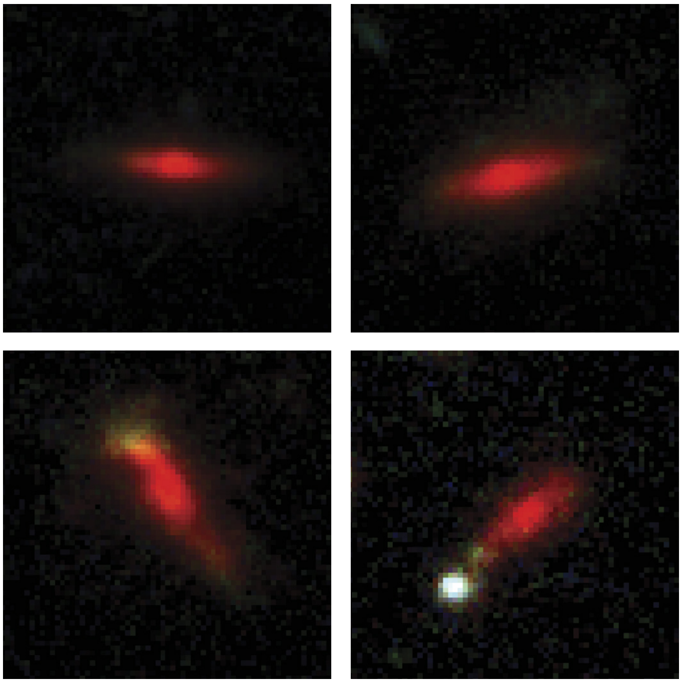
It appears these distant galaxies generated their calm from within — not by finding inner peace, but rather with an inner dragon that burns them out. One distant galaxy, GS-9209, appears to have actively formed stars for 200 million years but then gone dormant for a full 450 million years before we observe it 1.25 billion years after the Big Bang. At its core, a supermassive black hole, with the mass of a half billion Suns, is blasting out radiation as material spirals inward and attempts to feed the black hole. In nearby galaxies, we see such jets heat up surrounding gas, preventing it from cooling and forming stars for billions of years. However, we did not expect supermassive black holes to be common in the early universe, since they would not have had much time to form and grow (*S&T:* Jan. 2017, p. 24).

Recently, one of us (Larson) discovered a supermassive black hole



◀▲ **SUNRISE ARC** This knotted streak of light is a distant galaxy, its image lensed, magnified, and multiplied by the gravity of the cluster WHL0137 (facing page, composite using eight filters). The above image is colorized to make emission from star-forming regions stand out in green (white circles). The four regions are actually the same star-forming complex. Star clusters also make multiple appearances (one circled here in orange). Earendel is the most distant star ever detected, seen when the universe was 900 million years old.

CLUSTER: NASA / ESA / CSA / D. COE (STSCI), IMAGE PROCESSING Z. LEVAY (STSCI); SUNRISE ARC CLOSE-UP: NASA / ESA / CSA / D. COE (STSCI), IMAGE PROCESSING J. DEPASQUALE (STSCI)



▲ **EARLY DISKS** With only a month of JWST data, astronomers found a dozen dusty disk galaxies shining at us from more than 10 billion years ago. The farthest appears as it was when the universe was only 1 billion years old. These galaxies are invisible to the Hubble Space Telescope.

E. J. NELSON ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2023

earlier than previously thought possible. Observed just 570 million years after the Big Bang, this black hole has the mass of about 10 million suns. That's a few times the mass of the black hole at the center of our own Milky Way, but in a tiny galaxy about 5% the size of our own. Other teams have spotted hints of large black holes in small galaxies at even earlier times. It's hard to imagine black holes growing so big so early in cosmic history. How could a black hole have achieved this remarkable growth spurt?

First, it must have started out big. There are primarily two ways this could happen. One option is that it might be a remnant of one of the very first stars to form in the universe, called Population III stars. We have yet to see one of these stars, but we believe each one was big, burned hot, and died young in a supernova, finally leaving behind a black hole with the mass of 100 suns. But at this mass, the object would still not have enough time to reach the observed mass of 10 million suns by steadily eating gas. Instead, it would have needed several bursts of intense feeding to quickly grow by a factor of a million, which seems implausible.

Alternatively, the black hole could have started out from an even bigger seed, as an enormous gas cloud that skipped forming stars altogether and instead collapsed directly to form a black hole with a mass closer to 30,000 suns. Such black holes are still theoretical and would require very specific conditions to form. But if such an object did arise, then theoretically it could have grown quickly but steadily to the observed size. More JWST observations already under way will help shed light on this conundrum.

Did JWST Break the Universe?

One of the first science results from JWST appeared to break our understanding of galaxy formation — or even cosmology. Six anachronistic galaxies were determined to be too massive too soon (*S&T:* Dec. 2022, p. 8). One appeared to be as massive as our Milky Way just 700 million years after the Big Bang. It was as if you'd planted a sunflower garden and woke up the next morning to find some of the plants had already grown to be eight feet tall.

This result was reported in the first weeks of JWST science and generated enticing headlines. Papers with proposed solutions quickly followed. Some accepted the results at face value, explaining how they could upend our current cosmological model, Lambda CDM (*S&T:* Mar. 2022, p. 14). Additional matter and dark energy in the early universe could accelerate the growth of galaxies and the expansion of the universe, these solutions suggested. But that proposal would also imply that the universe is a billion years younger than the current age estimate of 13.8 billion years, which would be hard to reconcile with measurements.

Other papers presented less sensational solutions. Perhaps smaller stars were less likely to form at these times, some argued. Radiation from the cosmic microwave background has a temperature of 2.7 kelvin today, but it was a bit warmer (about 30K) when these galaxies existed. The radiation would have kept gas a bit warmer, suppressing the formation of smaller stars. If many small stars are missing, then these galaxies would actually have much less mass than originally measured, perhaps only 10% the mass of our Milky Way.

Alternatively, jets from supermassive black holes may contribute some of the light we see, leading us to overestimate how many stars, and thus how much mass, the galaxies have. This adjustment could also bring the galaxy masses down to one-tenth of the Milky Way's. While such heft would still be impressive for the time, current theories do allow for a few galaxies that massive 13 billion years ago.

However, two survey teams recently estimated the masses for hundreds of early galaxies and found no clear signs of overly massive objects: All the galaxies appear to fit comfortably within predictions. Future JWST observations at longer, mid-infrared wavelengths — which can tell us more about the stellar populations and whether there's a big black hole present — will help us tease apart how massive the galaxies really are.

Too Soon?

JWST is revealing exciting numbers of galaxies in the early universe. So just how far back have we seen? As we did with Hubble, astronomers are already pushing the limits of JWST — we spot tiny, faint galaxies in the images, and we struggle to discern their distances from their feeble light. Confirming their distances requires spectroscopy, which spreads the light from each galaxy into a rainbow, each color its own wavelength. By detecting the fingerprints of elements at specific wavelengths, we can measure a galaxy's redshift.

Some of the very first JWST spectra swiftly confirmed

galaxies in the universe's first 700 million years. More distant galaxies become more challenging because they are fainter and their spectra redshift to even longer wavelengths, where even JWST is less sensitive.

Emma Curtis-Lake (University of Hertfordshire, UK) holds the record for the most distant galaxy confirmed with a spectrum: JADES-GS-z13-0 is observed 98% of the way back to the Big Bang, when the universe was just 320 million years old. Curtis-Lake and the JADES team have confirmed that galaxies existed 13.5 billion years ago (*S&T:* Apr. 2023, p. 8). Finding a galaxy this distant so early in JWST's mission was very impressive and also comfortably within theoretical expectations.

The current picture emerging is that we are doing well identifying galaxies 320 to 600 million years after the Big Bang. Spectroscopy has now confirmed at least 20 galaxies at these distances. We celebrate these discoveries as refreshing and even a bit surprising after the number deficits suggested by Hubble at this early epoch. Most astronomers did not expect to find and confirm galaxies this distant so soon with JWST. And we certainly were not expecting to find galaxies even more distant.

But astronomers have identified some galaxies that might date back to even earlier times. One galaxy discovered in the first images from the CEERS survey appeared to date back to just 250 million years after the Big Bang. Not only was this galaxy shockingly early, but it was also unexpectedly bright. This brightness gave astronomers confidence they could obtain a quality spectrum to confirm the light's redshift, and from it calculate the true age. Their proposal was accepted, and observations were scheduled for March 24, 2023. It was the moment of truth. Would we need to rethink some of our basic understanding of early galaxies and the universe? Or would this galaxy turn out to be closer to us in a more recent era, as some predicted?

When the data came down, the result was immediate: We actually observe this galaxy 1.2 billion years after the Big Bang, much later than initially estimated. Spectral signposts of oxygen and hydrogen glare at us intensely from afar. These elements glow so brightly that they affect the colors we see in the images in a specific way that mimics a more distant galaxy. This could only happen for a galaxy at that specific distance if it's also very dusty and bursting with intense star formation to generate those strong spectral features. The universe had played a clever cosmic prank, and astronomers nearly fell for it.

JWST images have already revealed many more galaxies we need to check, including other very distant candidates that could yet rattle our understanding of the universe. It's not that we don't expect to find galaxies 250 million years after the Big Bang — we do, just not yet. They should be so rare and faint that it should take us longer to find them with JWST, using one of three methods: We can observe much larger areas of the sky with surveys like COSMOS-Web, already under way; we can use gravitational lensing to magnify the distant universe, as programs like Cosmic Spring, PEARLS,

The Far Stuff Is Made of Star Stuff

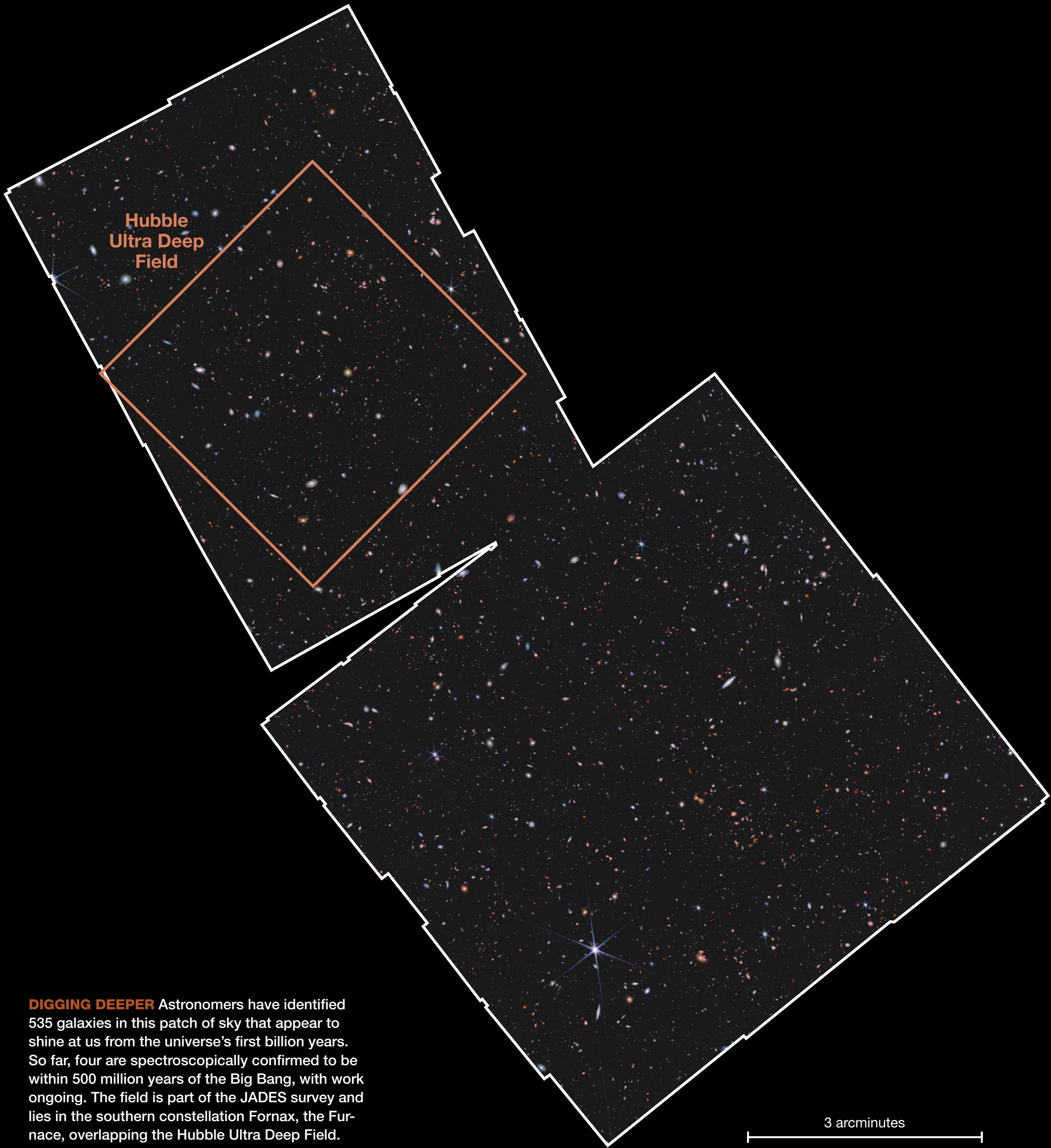
Carl Sagan famously said we are all made of star stuff. But the star stuff in our bodies wasn't around in the beginning. The Big Bang produced hydrogen and helium and little else (*S&T:* May 2022, p. 20). It took generations of stars forming heavier elements and spreading them throughout the cosmos to eventually enrich our Sun and our planet with the chemical stuff of life.

JWST is revealing our elemental history in greater detail and at earlier times than ever before. By taking spectra of distant galaxies, JWST can see the fingerprints of different elements and measure their quantities. Galaxies in the early universe had lower amounts of heavy elements like oxygen compared with galaxies today. But these heavy elements were still there.

One of the holy grails for JWST is to discover the very first pristine stars and galaxies composed of *only* hydrogen and helium. We have yet to find them. We find heavy elements in place as early as 430 million years after the Big Bang in the galaxy GN-z11. Its spectrum reveals at least six different elements: hydrogen, oxygen, carbon, neon, magnesium, and nitrogen. The most common elements in the air we breathe — nitrogen and oxygen — were already plentiful enough in GN-z11 to be observed in its light that traveled almost 13.4 billion years to reach us.

Seeing heavy elements like carbon so early in the universe was unsurprising to astronomers. Most of us worry we'll never see pristine stars. Heavy elements help gas cool and condense. Without these elements, pristine gas must come together in greater volumes before gravity will cause it to collapse, fuse atoms, and catch fire. That's why we expect long-theorized "Population III" stars to be oversized, burn extra hot, and die young, exploding after just a few million years and spreading their star stuff — including the heavy elements forged in their cores — throughout their host galaxies. Subsequent generations of stars would form enriched with elements like carbon, nitrogen, and oxygen, and these are the stars we see.

Of course, it is only the beginning of JWST's mission, and we will continue to analyze the spectra of distant galaxies to measure the buildup of star stuff over cosmic time and search for those pristine Pop III stars.



DIGGING DEEPER Astronomers have identified 535 galaxies in this patch of sky that appear to shine at us from the universe's first billion years. So far, four are spectroscopically confirmed to be within 500 million years of the Big Bang, with work ongoing. The field is part of the JADES survey and lies in the southern constellation Fornax, the Furnace, overlapping the Hubble Ultra Deep Field.

and others are doing; and finally, we can observe a JWST Ultra Deep Field, as we did with Hubble. The JADES and NGDEEP programs have begun taking very deep images, staring for days at small patches of the sky. But we have yet to fully push JWST to its limits. Only then can we obtain a more complete census of galaxies in the early universe.

Much More to Come

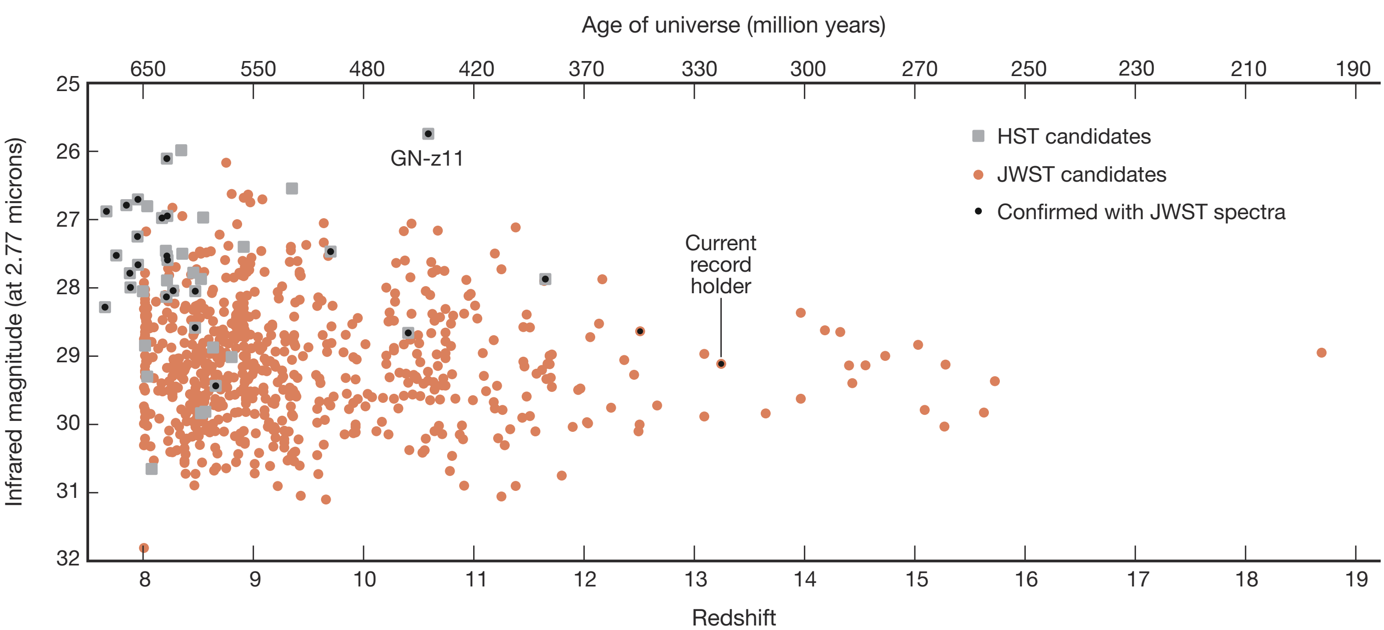
The first act on the cosmic stage is beginning to come into focus. With Hubble, we could see only a few scenes with fewer characters than expected, but JWST is now revealing many more players in the early universe. It is a great triumph. There are many early galaxies to be studied, but not too many to break our models. JWST has revealed a surprising diversity of galaxies in the early universe, including some like our Milky Way in size and/or shape. We have peered within distant galaxies to study young, intense star-forming regions alongside older star clusters that may persist to this day, as they do in our Milky Way. And we are tracking the buildup of "star stuff" over cosmic time, with elements like oxygen and nitrogen now observed over 13.3 billion years ago.

We are learning so much from these galaxies. More science papers are pouring in by the day, and this is just the first year of JWST's mission. The second-year slate of JWST observing programs was recently announced. Many more programs will observe distant galaxies, while others will observe objects like stars and exoplanets within our own galaxy. There is much science left to do; many questions remain. We have yet to discover the first, pristine stars and galaxies that lit up the universe. And while our cosmological model still works well, it is admittedly a patchwork held together by the mysteries of dark matter and dark energy. Fortunately, after a near-perfect launch, we are cautiously optimistic about a 20-year lifetime for JWST, giving us time to explore the universe, solve some mysteries, encounter new ones, and explore some more!

Apollo 8 astronaut Bill Anders famously said, "We came all this way to explore the Moon, and the most important thing is that we discovered the Earth." With JWST, we have looked back in time almost to the beginning and been reminded what humanity can accomplish when we work together. Some 20,000 engineers and scientists across 14 countries worked together towards a common goal to achieve an incredible success with JWST. Now thousands of astronomers are working around the world with JWST images and spectra to unravel some of the universe's greatest mysteries.

The human story is a remarkable journey that began 13.8 billion years ago. Born from the stars and simple elements, we have developed the technology to look back in time and study our origins. We can't wait to share more of the discoveries we make about the early universe and the first chapter of our cosmic history.

■ Astronomer **DAN COE** (Space Telescope Science Institute and Johns Hopkins University) leads the Cosmic Spring team that observed distant lensed galaxies in JWST's first year, with more to come in year two. Astronomer **REBECCA LARSON** (Rochester Institute of Technology) works with the COSMOS-Web and NGDEEP teams to find galaxies in the early universe.



▲ **(NEARLY) THE DAWN OF TIME** Astronomers have found hundreds of faint, red galaxies using JWST. Most of these lie in the JADES fields, two patches of sky — one in Fornax (Southern Hemisphere and facing page), the other in Ursa Major (Northern Hemisphere). Based on the galaxies' appearance (or disappearance) in different filters, researchers estimate how far back in cosmic time each galaxy lies. But astronomers need spectra to confirm a galaxy's true distance (black dots). Some of these preliminary distances may prove to be overestimates; we are still in the early days of data analysis. JADES-GS-z13-0 is the farthest galaxy confirmed so far, and GN-z11 shows hints of a supermassive black hole.

The James Webb Space Telescope's first images captivated the world last year, revealing the billowing folds of a stellar nursery, a dazzling rendezvous of galaxies, and other cosmic treasures in stunning detail (*S&T:* Nov. 2022, p. 12). But a few hundred miles above the buzz on Earth, another famous telescope continued to quietly go about its business.

The Hubble Space Telescope, our trusty observer of deep space, recently rounded out three decades in service, and it's still snapping photos. Even as many of us turn our attention to a younger observatory, scientists are working to make the most of this old one.

One of the projects that has helped do that is "Gems of the Galaxy Zoos." Zoo Gems is an unusual project: Rather than being a targeted proposal for a specific research study, it pulled together an assorted list of galactic targets to plug the holes in Hubble's schedule. Although it grew out of an online citizen-science effort, Zoo Gems went beyond volunteers' usual task of clicking through galaxies and sorting them by shape. Instead, it drew on a decade's worth of curiosity and conversation among "Zooites" to turn Hubble's gaze on some of the universe's most mysterious inhabitants.

Cosmic Community

For astronomers, enlisting the public can bring huge practical benefits. As ground-based telescopes churn out gargantuan maps of the sky, for example, volunteers can help sift through the data (*S&T:* Jan. 2023, p. 20).

The Galaxy Zoo project was born in 2007 to lend a hand — or, as it grew, many thousands of hands. In its early days, the online platform showed users deep-space images from the Sloan Digital Sky Survey and posed some simple questions: Is the galaxy in the image a spiral? Are its arms clockwise or counterclockwise?

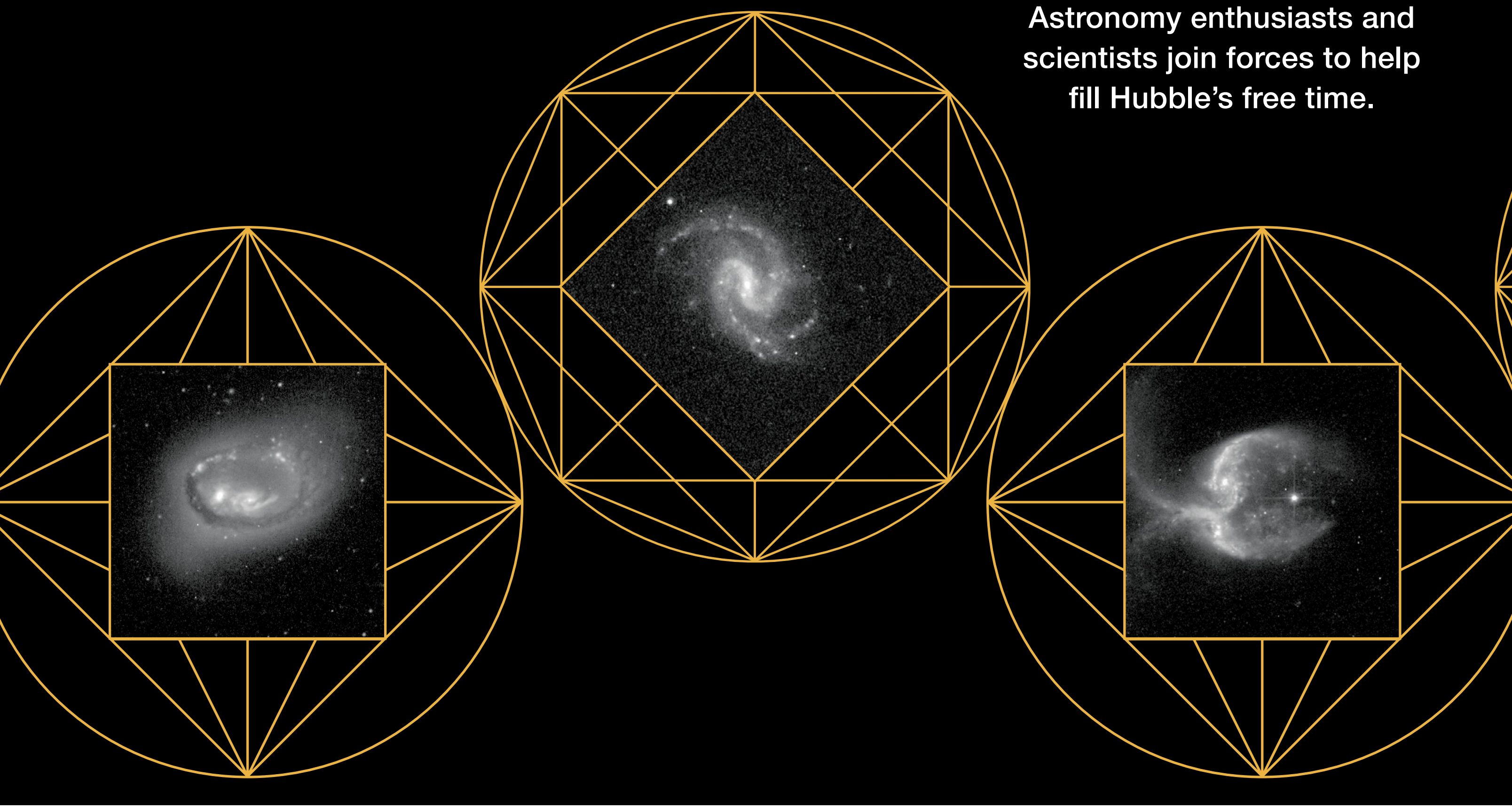
But it soon became clear that some Zooites wanted to do more than just classify galaxies. "I might possibly have believed the breadth of interest at the outset," says William Keel (University of Alabama), a member of Galaxy Zoo's science team. "But the depth that some of the volunteers went into, I don't know if I would have bought it to begin with."

The platform's discussion forum buzzed with activity: users pondering odd galaxies, asking questions, writing space-themed limericks. Christine Macmillan, a retired plant scientist and planetarium presenter, joined Galaxy Zoo in 2008 and eventually became a forum moderator. She dug

GEM SHAPES: KOVALTO1 / SHUTTERSTOCK.COM; IMAGES: NASA / STSCI, ESA, GALAXY ZOO TEAM, AND W. KEEL

Unearthing Galactic

Astronomy enthusiasts and scientists join forces to help fill Hubble's free time.



into topics from redshift to stellar spectra and posted thorough explainers for other volunteers.

"Just classifying the shapes is easy enough, because there are standard instructions," Macmillan says. "But once people start looking, they want to learn more." In 2014, she started a thread called "Objects that need more research," where volunteers traded thoughts on galactic oddballs they'd come across — such as objects that looked warped despite having no visible neighbors to yank on them.

"The best part of my day was getting to work and seeing what had been posted on the forum," Keel recalls. Ultimately, he says, the discussion board "turned out to be this enormous outlet for intellectual energy and skills and observation."

Guiding Hubble's Eye

In 2017, members of the Galaxy Zoo science team saw a chance to put that outlet to use. The Space Telescope Science Institute, which is responsible for Hubble's schedule, had issued a call: It wanted lists of observing targets to pull from as needed, to fill the gaps in time among objects on the telescope's docket.

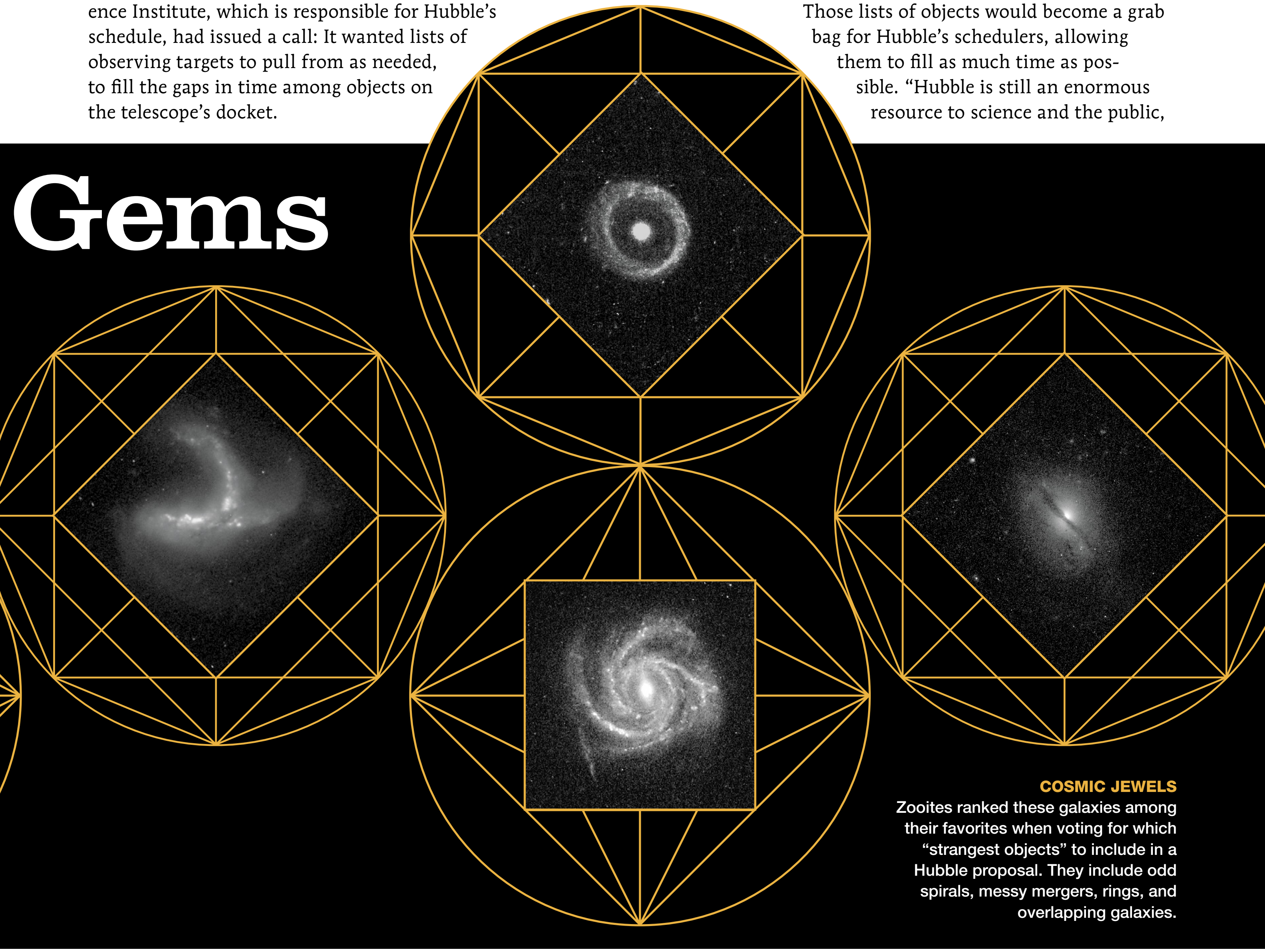
The Hubble team had long filled in the telescope's timetable with "snapshot programs," observations of 45 minutes or less slotted between its regular projects, says Tom Brown (Space Telescope Science Institute), head of the Hubble Space Telescope mission office. And yet, pesky snatches of unscheduled time remained.

"It just seemed like a waste to be throwing that time on the floor," Brown says. "Just a handful of minutes here and there, but still, it adds up."

And so the gap-filler program was born. Following the pilot, the institute asked astronomers to propose lists of gap-filler objects. These proposals would be far less formal than typical bids for time — two pages long and without a required format — but they followed their own set of rules: The targets should be spread across the sky; exposures would be short, using Hubble's Advanced Camera for Surveys; and the data would immediately become public.

Those lists of objects would become a grab bag for Hubble's schedulers, allowing them to fill as much time as possible. "Hubble is still an enormous resource to science and the public,

Gems



COSMIC JEWELS
Zooites ranked these galaxies among their favorites when voting for which "strangest objects" to include in a Hubble proposal. They include odd spirals, messy mergers, rings, and overlapping galaxies.

and we want to use it as efficiently as possible," Brown says. "We want to maximize the scientific return of the telescope."

When he heard about the program, Keel thought, "Well, this is just what we've been looking for." Crafting a proposal, he took to the discussion forum. "Help us collect the strangest objects!" he wrote, and volunteers complied, combing through old threads to find their favorites. Project scientists shaped the categories of galactic "gems" that Keel eventually proposed, but the list bore the fingerprints of the Zooites. For categories with many candidates, participants voted on which ones should make the final proposal — a process handled partly by other volunteers.

This kind of project shows that citizen science isn't just a machine, something "you put your project in and out comes your result," says Ivy Wong (Commonwealth Scientific and Industrial Research Organisation, Australia), part of the Zoo Gems team and a co-leader of Radio Galaxy Zoo, the radio astronomy counterpart of the original effort. "It's not like that at all. It's like any collaboration — the communication has to be two ways."

Galactic Weirdos

The Zoo Gems project, selected alongside two other gap-fillers, kicked off in 2018 and will run through late 2023. Hubble has observed more than half of the mysterious targets, including compact star factories known as "Green Peas," elliptical galaxies that are blue instead of the typical red, and a rare class of radio galaxies.

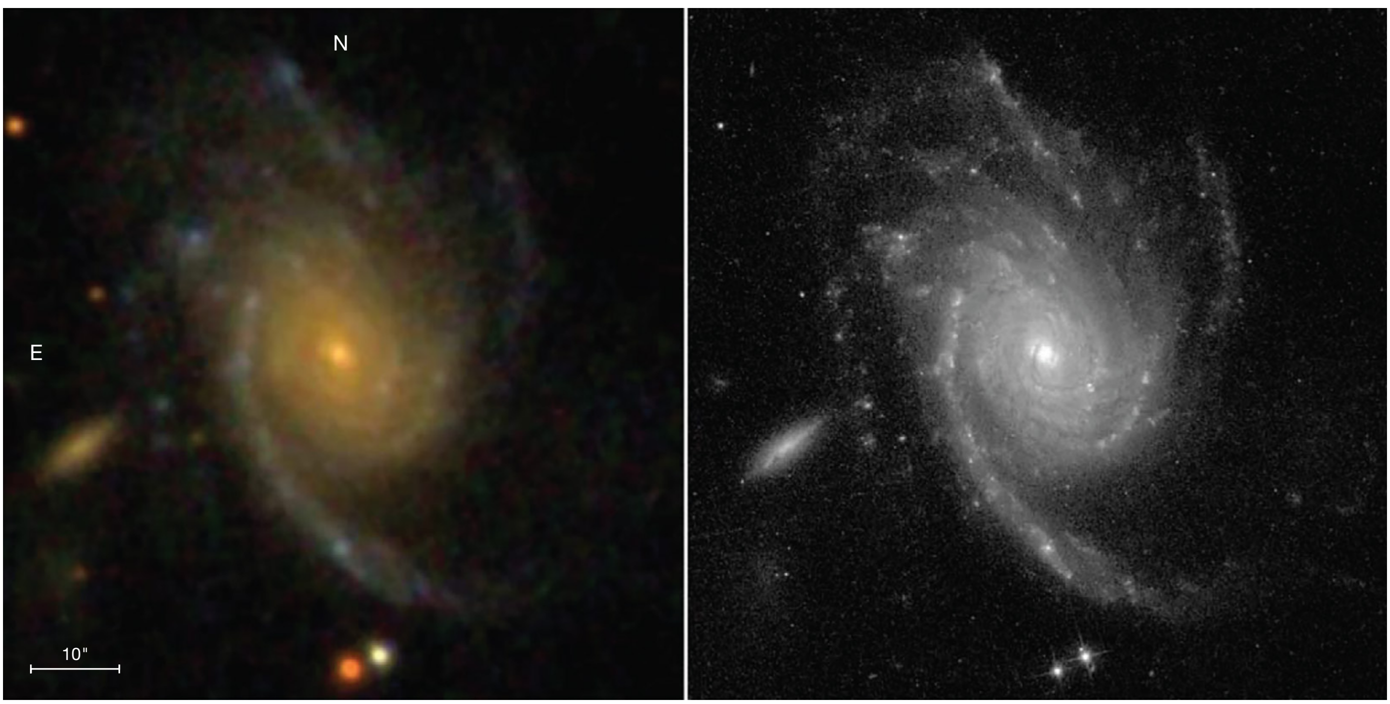
▼ **SUPERIOR VIEW** Zooites use Sloan Digital Sky Survey images (*left*) to classify galaxies like the red spiral UGC 3935. The details of the galaxy's swirl appear to great effect in the Hubble Space Telescope image (*right*) taken as part of the Zoo Gems project.

The breadth of unusual targets included in Zoo Gems is special, says Samantha Brunker (University of Connecticut), who was not involved in the project but has studied Green Pea galaxies. "They were able to select objects in many different categories," she says, producing a broad dataset that's "really beneficial for the community."

Plus, says Brunker, unusual objects can sometimes serve as tools for scientists as they untangle broader questions about the cosmos. "In the early universe, things that we think of as rare or unusual now might have been commonplace," she says. Take those Green Peas, first identified as a group by participants during Galaxy Zoo's early years. They're named for their small size and their color in Galaxy Zoo's ground-based images. The galaxies' hot young stars emit high-energy photons that excite the surrounding gas; the gas then belches out that energy at a wavelength the images show in green.

Green Peas are rare in the nearby universe, but scientists think they may be similar to the galaxies responsible for a major transition in the universe's early life. They have high star-formation rates and low metal content, and they leak photons capable of stripping away the electrons of hydrogen atoms. Those characteristics suggest they may be doppelgängers of the early galaxies that spurred the Epoch of Reionization, converting the universe's hydrogen into plasma (*S&T:* April 2018, p. 14). If so, then studying the nearby analogs could help us understand the traits of early galaxies, which are more difficult to analyze.

In fact, Webb recently spotted some early galaxies that researchers say look remarkably similar to the Peas. The objects are compact, and their spectra reveal similar levels of heavy elements as their modern-day counterparts. But Zoo Gems images suggest the Green Peas might not be perfect



analogs to the ones Webb sees. Thanks to carefully selected galaxies and Hubble filters, Leonardo Clarke (now University of California, Los Angeles) and others looked past the bright emission from the Peas' gas at the galaxies themselves. The young blue stars, they found, sit within a diffuse, redder region. If that color comes from older stars, then their presence could mark a key difference between Green Peas and early galaxies: Early galaxies are too young to have such a mature stellar generation. It's crucial to understand that star-formation history, and the role of older stars in galactic processes, to know what Green Peas can and can't tell us about the early universe.

◀ **YOU'RE BLOCKING MY VIEW** The spiral LEDA 2073461 lies in front of another, more edge-on spiral called SDSS J115331.86+360024.2. It's unclear how close the two galaxies are in reality, and there's no obvious sign of interaction. But the foreground galaxy has an intriguing double dust lane seen in other backlit Zoo Gems — is that normal?

Unusual galaxies can also help us understand the universe today, Keel says. He points to the Zoo Gems category of overlapping galaxy pairs. What's unusual there, he says, is not the galaxies themselves, but the fact that one sits neatly behind the other in telescopic images. It's like putting the foreground galaxy on a light table, he explains: With that backlighting, astronomers have another way to study the closer galaxy's dust.

Or, he says, consider these rarities: spiral galaxies with double radio lobes created by powerful jets, which launch during the voracious accretion activity of a central black hole. Most such double-lobed jets come from huge elliptical galaxies. Keel says the rare spiral hosts might reveal details about how these jets are produced.

To that end, Zihao Wu (Peking University, China) and others analyzed Zoo Gems images and collected 18 that they believe show true spiral hosts of these radio lobes. The galaxies tend to have high stellar masses for spirals, which implies they also have especially massive black holes. If so, then the black hole's mass might play a key role in determining whether it launches jets and how powerful those jets can be.

"They've done a really systematic job" of finding promising candidates for jet-launching spiral galaxies, says Clive Tadhunter (University of Sheffield, UK), who was not part of the research. But although this study reinforces past associations between mass and power, he cautions that the link between stellar mass and black hole mass isn't perfect. There's a lot more work to be done in untangling the factors that drive jet formation.

Ultimately, by inspecting galactic outliers, "we have a better idea of what's even possible," Brunker says. "If you're going to paint a whole picture, you can't leave out the weird things."

■ **MADISON GOLDBERG** is a science journalist based in New York City. She has written about topics ranging from sleep to sewer systems.

Join the Zooite ranks: **https://is.gd/galaxy_zoo**.

MULTI-ARM MERGER The Zoo Gem CGCG 396-2 lies about 520 million light-years away in Orion.

ESA / HUBBLE & NASA / W. KEEL (2)

 by Monica Young

The Case of the Uni

Astronomers imaging the blackness of space have found it isn't as dark as they expected.

Imagine you're lying in bed, reading. You've already turned off the overhead light and drawn the blackout shades for a good night's sleep. Before you tuck in, you turn off the lamp on your night table, too. Yet even after all that, there's still a glow permeating the room. Where is this radiance coming from?

This is the mystery astronomers are finding themselves in, although their "room" is the entire universe. Even after turning off the lights — that is, accounting for any possible light source that could affect their measurements — the Long Range Reconnaissance Imager (LORRI) aboard NASA's New Horizons spacecraft is still seeing a visible glow.

Some glow is expected. Unlike the relic radiation from the Big Bang, astronomers expected a background smear from distinct sources, such as dim and distant stars and galaxies. Since cameras can't detect the faintest of these sources individually, their light should combine to become the *extragalactic background light* (EBL).

So astronomers weren't surprised to find EBL — in fact, they'd spent decades searching for it. The real surprise is just how much of it there is. Using LORRI, researchers found twice the background glow that models had predicted. If these results hold up, they might end up revealing that there's more to the cosmic history of stars and galaxies — or maybe even more exotic matter — than we yet understand.

Zodiacally Bright Skies

The EBL long evaded detection because there are so many foreground lights to turn off. The brightest of these is the *zodiacal light*, sunlight scattered off dust that's sprinkled throughout the plane of the inner solar system (inside Jupiter's orbit). Zodiacal light is visible to the unaided eyes of earthbound observers, at least those under dark skies, so it may come as no surprise that it far outshines any background glow in the universe.

That's not to say that astronomers haven't tried to peer through that bright veil. In a series of studies published between 2002 and 2007, Rebecca Bernstein (now at Carnegie Institution for Science) used Hubble Space Telescope data to try to pin down the background glow. Ultimately, though, those measurements were only able to put a limit on how bright the EBL *might* be, rather than actually detecting it.

Other measurements did appear to detect the EBL, although those finds remain contested. Some of these came from the Cosmic Infrared Background Experiment (CIBER), which flew aboard multiple sounding rockets to measure the near-infrared sky from above Earth's atmosphere. Shuji Matsuura (Kwansei Gakuin University, Japan) and colleagues used data from CIBER's spectrometer from two flights taken in 2010 and 2013 to detect the EBL at infrared wavelengths. They found that no matter how they modeled the zodiacal light, they still found more extragalactic light than they were expecting, albeit with a lot of wiggle room in the results.

An alternative method to measuring the EBL came from a surprising source: gamma rays. These high-energy photons are known to interact with visible and infrared light, disappearing in the process. So what astronomers do is measure the light from distant, bright gamma-ray sources known as *blazars*. As the gamma rays travel to Earth, they tangle with intervening visible and infrared photons. Estimating how many gamma rays have disappeared along the way leads to an indirect measure of the EBL. Some of these measurements found no extra light; others left room for interpretation.

NASA / ESA / S. BECKWITH (STSCI) / HUDF TEAM

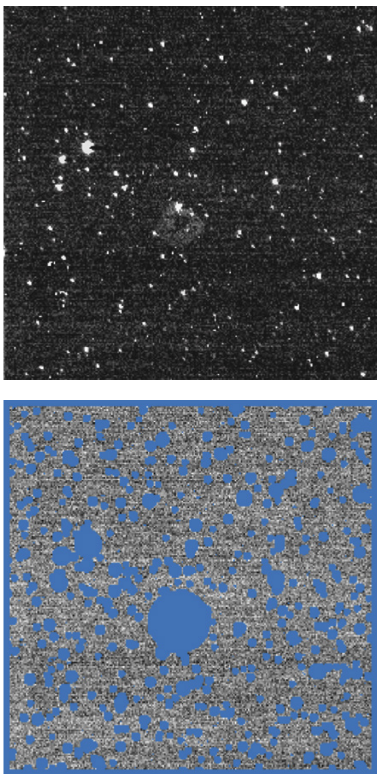
verse's Extra Light

▲ **THE SPACE BETWEEN** Some astronomers find that, in the space between stars and galaxies, there's a subtle glow (not visible here) that can't be explained by more distant — and thus unresolved — stars and galaxies. What is the source of this background light?

Out Yonder

This was the state of affairs when LORRI entered the picture. New Horizons carried this imager to Pluto in 2015 (*S&T:* Nov. 2015, p. 18) and to 486958 Arrokoth in 2019 (*S&T:* Apr. 2019, p. 8) in order to image these fascinating worlds in the outer solar system. But Tod Lauer (NSF's NOIRLab), Marc Postman (Space Telescope Science Institute), and others realized the camera could be put to a different purpose. By traveling to the outer solar system, the spacecraft and the camera it carries have passed far beyond the zodiacal dust. That's akin to removing the bedside lamp from the hypothetical room, rather than trying to shield it from view.

Lauer, Postman, and fellow members of the New Horizons science team led two studies, one in 2021 and another in 2022, that used a selection of LORRI images to look for the EBL. And they found it. The detection is significant to more than 10 sigma — in other words, there's almost zero chance this measurement is a fluke. The EBL the team measured is surprisingly bright, between 14.9 and 17.8 nanowatts per square meter per steradian. (The units indicate the power coming from each unit area on the sky and landing on each unit area of the detector; hereafter nW/m^2/sr.) The result is about twice as bright as expected from faint, unresolved stars and galaxies.



SYMONS ET AL. / *ASTROPHYSICAL JOURNAL* 2023

▶ **MASKED** The first step in looking for background light is to remove the light from stars and galaxies. The image at bottom shows the same LORRI image as at top, but with a mask applied to remove light from stars and galaxies. An optical ghost at the center, caused by a bright star just outside the field of view, is also masked out.

Even without the zodiacal light in play, there's a lot that goes into this accounting to cancel out all the light from stars and galaxies. First, the team removed the objects actually detected in the images. Then they removed the dim halo of light around stars and galaxies just outside LORRI's field of view. The team also subtracted out the light coming from dust scattered along the galactic plane as well as light from optical or camera defects.

The remainder ought to come from the light of faint, unresolved sources, mostly galaxies. But according to galaxy counts made using Hubble observations, faint galaxies should only contribute 8 nW/m^2/sr, explaining roughly half of the EBL that LORRI detects.

Postman says his initial reaction wasn't elation at discovery but rather, "What did we miss?" Right away, the researchers went through every possible source of light other than stars and galaxies. After all, Postman adds, "We are using the LORRI camera on New Horizons in a way for which it was never intended." And the team was thorough. The researchers checked for poten-

tial sources of noise within the detector and without. They even checked if radiation from New Horizons' nuclear power source could have created visible "sparks" of *Cherenkov light*. But no, the extra light appears to be astronomical.

Around the same time, Teresa Symons (then a graduate student at Rochester Institute of Technology) was undertaking a separate study of LORRI data for her PhD thesis. Whereas Lauer's team in 2022 used a set of 16 targeted images, Symons selected data from the full LORRI archive, amounting to 529 images that included some grainier ones as well as some taken when New Horizons was still en route, just past Jupiter's orbit.

The analysis of these data was extensive and took years, but it didn't make the problem go away. In the end, the EBL Symons' team detected was even brighter than what Lauer's team had measured — between 19.4 and 24.6 nW/m^2/sr.

How can two analyses of data from the same camera give such different results? The answer is once again dust — this time the stuff in our galaxy. Like the zodiacal dust that permeates the inner solar system, dust is found all along the galactic plane, and it, too, scatters starlight. This *diffuse galactic light* is much fainter than zodiacal light, and unlike with zodiacal light, we can't simply leave our galaxy to escape it. There are many methods of estimating just how bright that scattered light is, and they all give different answers. Symons' and Lauer's teams used different methods. While their exact results differ, both teams find extra background light that they can't explain.

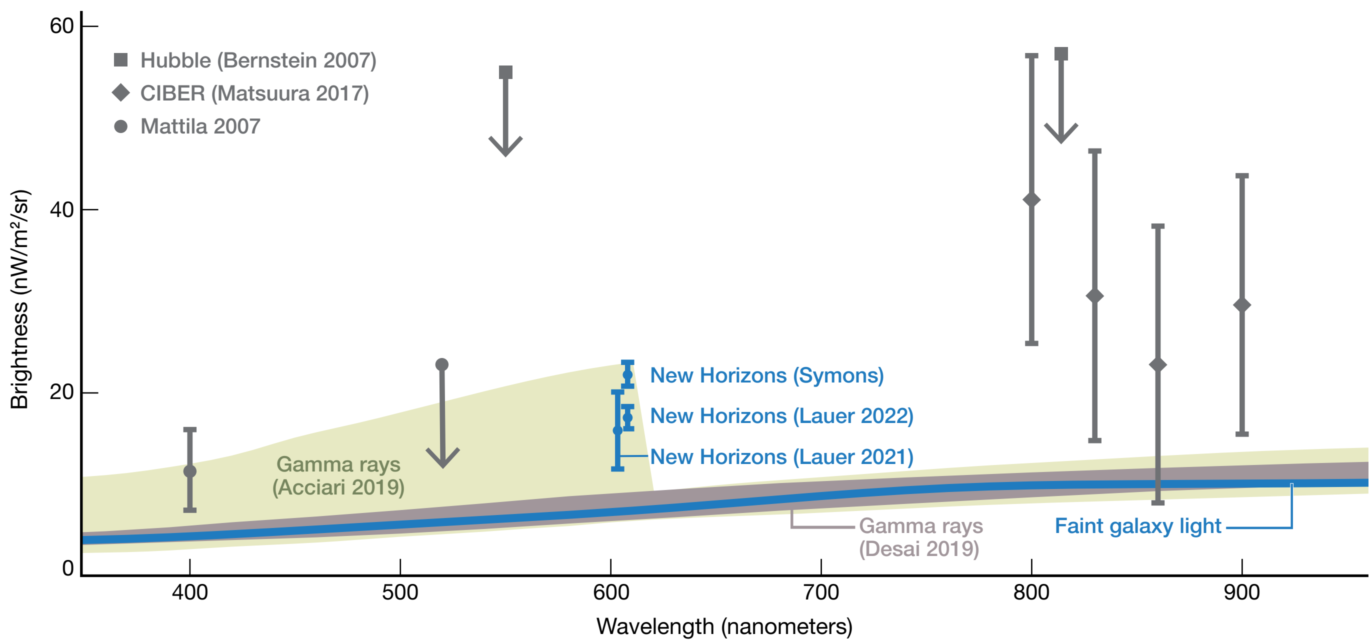
Potential Origins

Perhaps the easiest culprit to blame would be faint galaxies. Using the Hubble Deep Fields, astronomers have counted how many faint galaxies there should be relative to the bright ones. But what if that number is wrong? Indeed, in 2016, Christopher Conselice (now at University of Manchester, UK) found that Hubble's various deep fields in fact *aren't* finding all the faint galaxies.

However, distance affects the wavelength observed. LORRI can see galaxies' visible light out to 1 billion years after the Big Bang (that is, to a redshift less than 6). But many of the galaxies that Hubble's missing are more distant. As light travels through the expanding universe, it loses energy, reddening toward infrared wavelengths and leaving little light left in the visible range. The James Webb Space Telescope (JWST) will be able to pick up these distant galaxies, but LORRI, a visible-light imager, would never see them or their light.

It's possible that the extra light comes from faint galaxies that aren't quite so far away. But when Darby Kramer (Arizona State University) tested this possibility, she found that even if Hubble were missing some nearer faint galaxies, those galaxies couldn't provide all the unexplained light.

Lauer acknowledges it's hard to solve the problem with galaxies alone. He thinks some of the extra light might also be coming from lost stars. When galaxies collide, stars are the collateral damage, with some flung out by themselves into intergalactic space. Perhaps there are enough wandering stars to produce an unaccounted-for background.



▲ **HOW DARK IS SPACE?** This graph shows a representative sample of many attempts to measure the extragalactic background light at visible wavelengths. Surprisingly, recent analyses of New Horizons images (blue circles) have shown a total background glow brighter than expected from faint, unresolved stars and galaxies (solid blue line). Other direct measurements are shown as gray squares, diamonds, and circles. Meanwhile, some indirect measurements made via gamma-ray observations (gray shading) find a background consistent with unresolved sources, while other similar data modeled with fewer assumptions are less decisive (light green shading). In some cases, especially near Earth where the zodiacal light is so bright, there was no certain detection but only a limit to how bright the background could be; these upper limits are marked as downward arrows.

BEATRIZ INGLESSIS / S&T; SOURCE: LAUER ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2022

Alternatives beyond stars and galaxies start to become more exotic. Some teams have suggested that still-theoretical dark matter particles — either *axions* (*S&T:* Jan. 2021, p. 16) or axion-like particles — might decay into photons that contribute background light. But while astronomers aren't willing to rule out the possibility, neither do they seem eager to jump on that particular bandwagon. "It's pretty far down the list right now," Postman says, "but it's on the list."

Lauer, for his part, doesn't advocate for any particular solution. He asks with a straight face: "Could it be a giant squid that's glowing? Well, you know, maybe so, we've never been out there. Maybe there are giant squids."

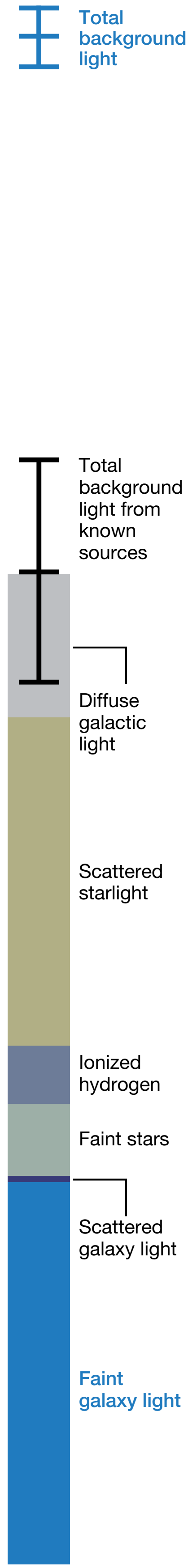
Another possibility remains that the extra light isn't there at all. While the detection is significant in a statistical sense, that doesn't mean it has to be real. There could be something that both Lauer's and Symons' teams have overlooked.

"I am positive it's something systematic in New Horizons," says Rogier Windhorst (Arizona State University).

Windhorst runs a program called SKYSURF, one of the largest studies of Hubble's archival observations. Together with colleagues, he has trawled scads of images that the iconic telescope has taken over the past three decades, looking for light — in this case at near-infrared wavelengths — in between those images' stars and galaxies.

Hubble has some advantages. One is the sheer number of images researchers have to work with. Another is that it can resolve most background galaxies, rather than relying on a model of how much background light those galaxies would produce. But it also has significant disadvantages. Not only is it peering through the bright shine of the zodiacal light, but its images are also notoriously difficult to calibrate.

"Hubble has 15 sunrises and 15 sunsets per day, which is *horrifying*," Windhorst declares. The resulting heat fluctuations create false signals in Hubble's camera that are difficult to subtract. Due to the telescope's vagaries, SKYSURF has only measured upper limits on what the EBL could be, and they are consistent with previous observations — including those from New Horizons.



▶ **SOURCES OF LIGHT** This stacked bar chart shows the contributions from various light sources to the extragalactic background light of a New Horizons field that Lauer and colleagues examined in 2022. The background light measured in that field (blue cross at top) exceeds all known contributions, implying an extra, unknown source. (The two vertical lines indicate the range of possible values in both the background light measurements and the expected contributions from known light sources.)

BEATRIZ INGLESSIS / *S&T*; SOURCE: LAUER ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2022

Now, Windhorst is applying the same type of analysis to observations taken by JWST, which sees no sunrises or sunsets at all thanks to its sunshield. The recent analysis has resulted in only loose upper limits so far, based on just a few months of observations. More images and a better understanding of JWST calibration will help tighten the net.

Despite his doubts, though, Windhorst acknowledges that LORRI's position gives the New Horizon science team the advantage over both Hubble and JWST. "They're completely beyond the zodiacal light, and that's unique," he says. "They're doing a great experiment."

On the Case

Like so many fascinating questions in astronomy, the unexplained brightness of space remains an open case. But astronomers haven't run out of recourse. As New Horizons continues its flight out of the solar system, its LORRI camera is still snapping pictures. Lauer and others have asked for targeted imagery over New Horizons' extended mission to help them better account for or even diminish the contribution of the Milky Way's dust. Those images will also help them answer new questions, such as whether the background glow itself varies across the sky, which will in turn help astronomers understand its origin.

JWST holds promise, too, not only for measuring the EBL itself but also for testing the faint-galaxy scenario. While JWST doesn't see visible light, its sensitive infrared images might be able to tell us whether there are more faint galaxies in the nearby universe than expected.

Ultimately, the best bet might be an instrument made to order. Neither Hubble nor LORRI nor JWST were really designed to detect faint extragalactic background light. A camera designed for that purpose aboard an interstellar probe would do a better job, although such a spacecraft is likely decades away.

Another, nearer-term option is to place a camera (or make use of cameras already planned for) on another interplanetary mission. NASA's Europa Clipper is due to launch in October 2024 for the Jupiter system, and it will carry a LORRI-like visible-light camera. Beyond most of the zodiacal light, it will offer a new perspective on the EBL.

In the meantime, the mystery of the universe's extra light remains unresolved.

■ News Editor **MONICA YOUNG** wonders how many cosmic squids it would take to explain the extra background light.

Autumn Outreach

Offering views through your telescope to an audience is a rewarding endeavor.

Any astronomer who has witnessed that spark of interest in a youngster peering through a telescope for the first time or the utter amazement of a viewer taking their first look at Saturn understands the appeal of doing outreach. It's perhaps the most rewarding experience our hobby has to offer.

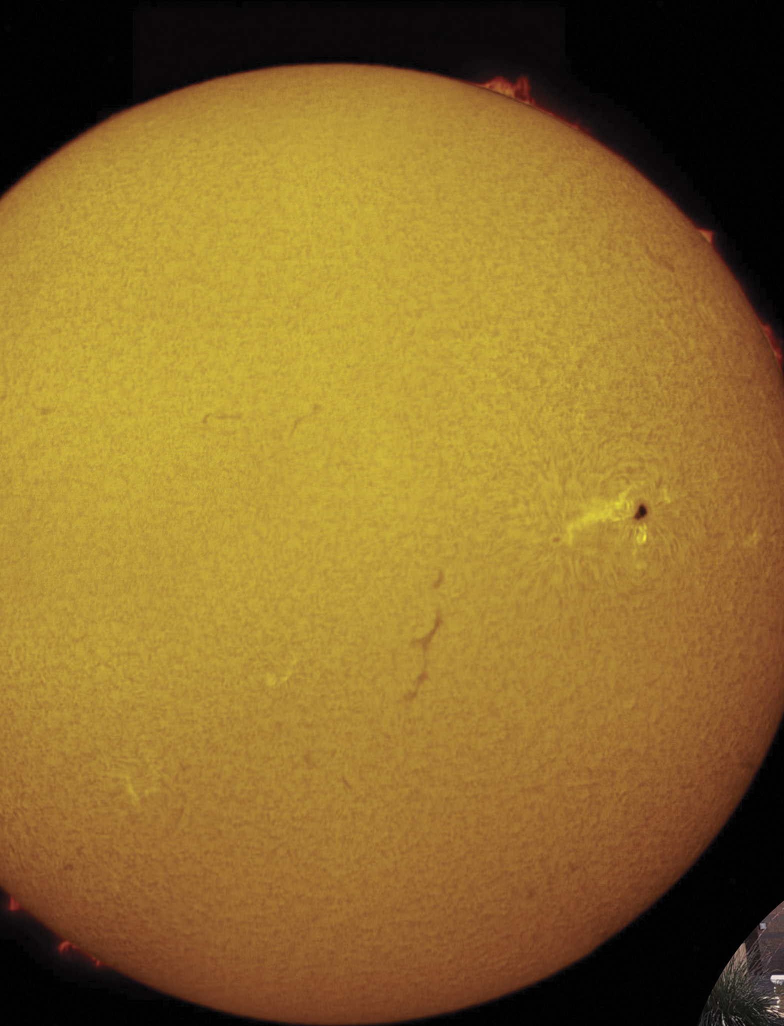
Astronomy outreach can be effective anywhere. Dark skies aren't necessarily required — we can enjoy the Moon and the brighter planets even in light-polluted cities. Nearly half of the outreach that I do is done in the daytime, observing the Sun. The only essentials are enthusiasm and a willingness to share your passion. Let's start with our daytime star.

OUTREACH UNDER THE SUN The author lives in southern Arizona where it's sunny all year round. A big part of outreach is inspiring children. All the events depicted here happened in or near Sierra Vista, often at public libraries.

Solar Sharing

The Sun is in a period of increasing activity right now and makes a particularly interesting target to share with an audience. The current 11-year sunspot cycle began in December 2019 and should max out in 2025, although recent evidence suggests an earlier peak may be in the cards. Adding to the appeal are two upcoming solar eclipses that will cross large portions of the continental United States. On October 14, 2023, an annular eclipse will traverse the western states from Oregon to Texas, over the Gulf of Mexico, and on into Mexico, Central America, and northern South America (see page 34). The path of the April 8, 2024, total solar eclipse crosses much of the continent from Mexico sweeping northeastward into Newfoundland. For those who can get to the path of totality, eclipses offer an unparalleled opportunity to engage the public. Even areas that will see only a partial eclipse can attract considerable interest — during the 2017 Great American Eclipse, my town saw only a 70% partial, but an outreach event that my astronomy club held still drew a huge crowd.

Eye safety should be your primary concern when observing the Sun (see the sidebar on page 30). Public events featuring solar observing demand constant vigilance to keep your audience safe. However, when viewed responsibly, our star is a fascinating target. You should learn the basics of the solar phenomena that your guests will see through your telescope. They'll want to know what a *sunspot* is and why it appears dark. You don't need to get too technical — I usually just say that sunspots are magnetic disturbances on the Sun's surface and explain that they appear dark because they're a bit cooler (around 6,300°F) than the surrounding areas (10,000°F).



If you share the more dramatic hydrogen-alpha view, you'll want to explain what a *prominence* is. Your guests are apt to call them "flares." I typically clarify by simply noting that flares are very short-lived events — not unlike lightning — that are rarely seen, while prominences are long-lived eruptions of plasma that can last for days or even months. Point out the long, dark features known as *filaments* and explain that they're arcs of *plasma* (ionized gas), just like the prominences, but seen face-on. And like sunspots, they appear dark because they're cooler than the Sun's surface below them.

The Moon

With K-12 students returning to their classrooms, the autumn months usually signal an uptick in outreach events aimed at kids. These are typically held in the early evening, often beginning in twilight, so it's usually a good idea to schedule school events near the first-quarter **Moon**. To me, no other object, not even Saturn, is as awe-inspiring as a waxing Moon in a telescope. Not only is it a never-fail attention grabber, it's also easy to catch before bedtime.

Kids are apt to take just a quick glance at the Moon without much consideration of what they're looking at. I like to employ a sort of Socratic methodology: I ask them to tell me — and their friends gathered around the telescope — what they see. And then I follow up with questions. Is the Moon all the same color and brightness? Once they acknowledge that the Moon does indeed have dark and bright areas, the next step is to ask if they see any differences between them. Are some surfaces smooth and others rough-looking? For young children, just getting them to notice such details is enough. Older kids can be further guided to speculate on why those surfaces might be different. How might they have formed? Questions like these might encourage viewers of all ages to be more observant.

At first-quarter phase, three of the Apollo landing sites are visible (see the image on page 31). I've had some pretty moving experiences guiding adults of the "Apollo Generation" to them, especially the Eagle's landing site (Apollo 11). It brings up all sorts of reminiscences and also sparks a number of teachable moments. With young and old alike, it can be a segue into discussing the upcoming Artemis missions, humankind's next great adventure on the Moon.

SUN: SEAN WALKER / S&T; OUTREACH PHOTOS: TED FORTE (4)

Safety First

Viewing the Sun is perhaps the most inherently dangerous activity in which amateur astronomers typically engage. Observers must *never* view the Sun with binoculars or a telescope without an appropriate filter. Make sure it's in good repair and free of cracks, scratches, or pinholes.

The safest way to observe the Sun is via projection. With a telescope or binoculars you can project the image of the Sun onto a white surface. The resulting image will show the larger sunspots and is an excellent way to safely monitor the progress of an eclipse. But you must be *very* vigilant: Take care to supervise children carefully when sharing the projected image of the Sun — a curious child might decide to take a direct look through the projecting device (or put their hand out to "touch" the image).

White-light solar filters for telescopes and binoculars should fit snugly over the objective end of your telescope — never on the eyepiece — and should cover the objective completely. Be sure your filter comes from a reputable source and check it for integrity every time you use it. Eclipse glasses and solar filter material for homemade filters must meet ISO standard 12312-2; see **https://is.gd/iso_standard**.

A Herschel Wedge or Solar Wedge is a prism device that can be used on refractors to safely view the Sun. It's not good for reflecting telescopes, though, as it may damage the secondary mirror. The wedge must be treated with care to avoid damage to its internal filters. Be sure to follow the manufacturer's recommendations for the size of scope with which you're observing. Take care during use as many types of wedges will have exposed hot surfaces where excess heat is vented.

A number of dedicated solar telescopes are available that can view the Sun in a narrow part of the spectrum such as hydrogen-alpha or calcium-K. These telescopes are generally very sensitive to shock and should be treated with extreme care. It's important to follow the manufacturer's recommendations for use and maintenance and to never remove any of their internal filters.

The Planets

The most popular request by far at outreach events is to view the planets. It's always a good idea to be aware of when each one will be visible. Of course, this magazine provides an overview of each planet's position on pages 41 and 46 and a detailed table of data on page 44. Happily, the gas giants augment the autumn sky this year. **Saturn** is well placed at sunset from mid-September through the end of the year. **Jupiter** is not far behind. By October, both planets will make excellent early-evening targets. Presenters showing the planets should arm themselves with some basic facts, both to add interest and to prepare for the inevitable questions. In my experience, the most frequently asked question regarding any planet is: "How far away is it?" I often respond with "almost a billion miles" for Saturn and "almost a half billion miles" for Jupiter. Not exact, but impactful and easy to remember. If you prefer to be more precise, Saturn is on average 886 million miles from the Sun; Jupiter averages 484 million miles. At the observatory where I do the majority of my outreach, we keep a cheat sheet with essential data, so we don't have to remember every statistic.

An analogy gleaned from a NASA website (**solarsystem.nasa.gov/planets**) provides a useful way to describe the relative sizes of planets: If Earth were the size of a nickel, Jupiter would be the size of a basketball and Saturn the size of a volleyball. About 1,300 Earths could fit inside Jupiter; nearly 800 Earths would fill Saturn. The public is usually delighted to hear that Saturn is less dense than water and would float in a bathtub if there was one large enough. I always get a chuckle by asking if it might leave a ring around the tub. There are many more interesting facts about these most remarkable objects that will intrigue a crowd, and it's always fun to have a supply of them at the ready.

Treasures of the Summer Triangle

Once twilight begins to fade, it's time to branch out into the deep sky. The bright signpost stars of the Summer Triangle, still high in the sky on autumn evenings, make finding a few showpieces a cinch even in bright moonlight. Vega, the fifth-brightest star in the night sky, will be among the first to appear in deepening twilight and can point the way to one of the most interesting multiple-star systems in the October sky. With Vega in your finder, **Epsilon (ε) Lyrae** will appear as a bright binary 1.7° to the northeast. Center Epsilon Lyrae in your eyepiece and pump up the power as much as conditions allow. Known as the Double Double, this fairly wide (some 209″ apart) binary star can in turn be resolved into two tight binaries. **Epsilon^1 Lyrae** splits into a pair of stars of magnitudes 5.1 and 6.1 that are 2.3″ apart, while **Epsilon^2 Lyrae** comprises 5.2- and 5.4-magnitude components separated by 2.4″. Challenge your guests to split the two close doubles for a fun exercise; ask them to describe the pairs' orientations to ensure that they are actually seeing them.

For more double fun, point your scope at the head of Cygnus, the Swan. **Beta (β) Cygni** (Albireo) is one of the most

TED FORTE

RESPLENDENT SELENE The Moon delights viewers of all ages. Asking questions of your audience gets them to think more deeply about the targets they're looking at. With the Moon, you can also point out elements like the Apollo landing sites (numbered at right), which provides a direct connection between humankind and our nearest celestial neighbor.

famous double stars in the heavens and for good reason. This lovely pair of stars of magnitudes 3.2 and 4.7 some 35″ apart exhibits a strong color contrast that makes them a striking couple. Observers tend to see slightly different hues — ask viewers to give their opinion on what they note. Appraisals will vary widely, but everyone will agree that the two stars are indeed of different colors, most often described as a vibrant blue and gold. Albireo, around 430 light-years away, may not be a true binary (which can give you more fodder for discussing, for example, the varied natures of double stars).

Before leaving the Summer Triangle, a stop at **M57**, the Ring Nebula, is in order. This most remarkable planetary nebula is sufficiently bright (magnitude 8.8) to see even in the typical light-polluted schoolyard or city park. With its obvious annular shape, it's striking enough to impress an audience. It's also rather easy to find, lying nearly midway between the 3rd-magnitude stars Beta Lyrae, or Sheliak, and Gamma (γ) Lyrae, or Sulafat, that form the base of the harp's parallelogram figure. The distance to the Ring hasn't been reliably established, but it's probably about 2,500 light-years away, which would make it — with an apparent size of 76″ — nearly 1 light-year across.

Among planetary nebulae, M57 is a fine example. These objects represent a late evolutionary stage in the lives of low- to intermediate-mass stars and form after nuclear fusion has ceased in the star's core. The star becomes unstable, expands, and sheds its outer layers into surrounding space. The hot, exposed stellar remnant then lights up the sloughed-off layers so that they glow. Planetary nebulae exhibit a wide range of shapes, and M57 is most likely a distorted torus, a sort of ghostly celestial doughnut. You probably don't need to be any more expansive than that to explain what these objects are.

Clusters — Globular and Open

Bright globular clusters make great outreach targets, and the autumn sky contains several notable examples, including **M15** and **M2**. Conveniently, both globulars lie in the same general swath of sky. To locate M15, start by identifying the star at the southwestern corner of the Great Square of Pegasus, Alpha (α) Pegasi, also known as Markab. From there, follow the line of the three bright stars Xi (ξ), Zeta (ζ),

▶ **RINGED WONDER** Saturn is a sure-fire hit with just about everybody. In fact, many — if not most — professional and amateur astronomers alike can trace the spark that lit their passion to their first view of Saturn through a telescope.

SEAN WALKER / S&T (2)

The public is usually delighted to hear that Saturn is less dense than water and would float in a bathtub if there was one large enough.

and Theta (θ) Pegasi leading southwest and imagine a dogleg angling northwest from 4th-magnitude Theta to 2nd-magnitude Epsilon Pegasi, or Enif. Extend that line by 4.2° beyond Enif to get to M15 (for reference, the outer circle on a Telrad is 4°). M2 lies 13° south of M15, about 70% of the distance between Epsilon Pegasi and Beta Aquarii (Sadalsuud). Both targets are bright enough to show in a finderscope. The globulars are visually fairly similar, so you might decide to focus on just one of the pair — M15 is just a little brighter, while M2 is a little more concentrated. Either will be impressive in an 8-inch or larger telescope, and I recommend using a magnification of 200× or more.

If the flow of the event allows the time and you sense enough interest from your guests, you might try to impart what makes different types of objects important to the study of astronomy. Regarding globular clusters, for example, I like to relate how American astronomer Harlow Shapley used their distribution in the Milky Way's halo to estimate the size of our galaxy and determine the Sun's place within it.

Open clusters are important laboratories for understanding stellar evolution. Once a collection of stars is identified as a gravitationally bound group with common proper motion, scientists can derive certain important assumptions. They can assume that the stars in the cluster formed together, condensing from the same cloud of dust and gas, and that they are all roughly the same age and at the same distance from Earth. Therefore, the only significant difference between cluster members is their mass. Since mass is of primary importance in the life cycle of a star, clusters provide an invaluable tool for understanding how stars evolve.

Be Quick

For those not using a Go To scope in their outreach, it's pretty important to choose objects that you can locate easily. Crowds will quickly lose interest if it takes you long to find a target. So make sure you know where your objects are, and study star charts ahead of time so you can swiftly guide eager viewers on their celestial trek.

There are several lovely open clusters in the fall sky, and the constellation Cassiopeia is a treasure trove of them. High in the northeastern sky on October evenings is **M52**. This is one of the richest open clusters in the Messier catalog — it's brimming with stars, probably numbering about 200 members. An 8th-magnitude topaz jewel appears to adorn the cluster, but this orangey star may not be a member. The central body of the cluster contains a number of uniformly bright stars atop a background of many faint glints. Extend the line connecting Alpha and Beta Cassiopeiae to the northwest a bit more than the extent of the stars' separation to arrive at the cluster, which shows well in binoculars and finderscopes. The relative ease of locating M52 makes it a reliable target for outreach events.

▼ **INTERESTING TIDBITS** The globular cluster M15 shimmers in Pegasus. While sharing the view of M15 (or M2 if you so choose), you can let your audience know that globular clusters are generally ancient, with the oldest clocking in at more than 13 billion years, which is nearly as old as the universe itself. They're also jam-packed with stars — on the order of hundreds of thousands.

▼ **STELLAR SCIENCE** This image of the open cluster M52 was acquired with a professional telescope. Viewers familiar with photos like these in magazines or online understandably can feel somewhat disappointed when they lay their eyes for the first time on such targets through smaller telescopes. Take advantage of these moments to inform your guests of other aspects of the objects, such as the astrophysics of the targets.

M15: SEAN WALKER / *S&T*; M52: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Galaxies

Let's turn to a galaxy to round out our menagerie of celestial objects. Almost everyone in your audience is likely to have heard of the Andromeda Galaxy and will be eager to see it. **M31** is high enough to enjoy soon after twilight fades on October nights. If you're lucky enough to be doing outreach under a dark sky, your guests will find it easily, as it's large and bright and visible to the naked eye.

Be prepared, however, for some disappointment from first-time viewers. Almost everyone has seen beautiful photos of the galaxy, and the view through the eyepiece might be a letdown. It's your job to re-excite them — I like to stress how very far away the object is and how ancient is its light. I ask my guests to imagine what the Milky Way might look like if they lived on a planet circling a star in that distant galaxy and had a telescope like the one they're looking through. Observers should be impressed by the sheer size of the object. At its distance of about 2.5 million light-years, the light from the near edge of Andromeda arrives about 200,000 years before the light from the far edge. Consider, you might suggest, that the entirety of recorded human history transpired in just a fraction of that interval. Tell them that Andromeda and the Milky Way are on a collision course, for example.

I've met a number of astronomers, both amateur and professional, who can trace their fascination with astronomy to a childhood encounter with an enthusiastic observer who took the time to share the view through their telescope. It's likely not an exaggeration to say that anyone who has done a lot of outreach has probably changed a life or two and brought considerable joy to countless others. I ask you, what better use of a telescope is there?

■ Contributing Editor **TED FORTE** is the outreach coordinator for his astronomy club in Sierra Vista, Arizona. For his work bringing astronomy to a larger audience, he earned the Astronomical League's outreach award (Master level) in 2008.

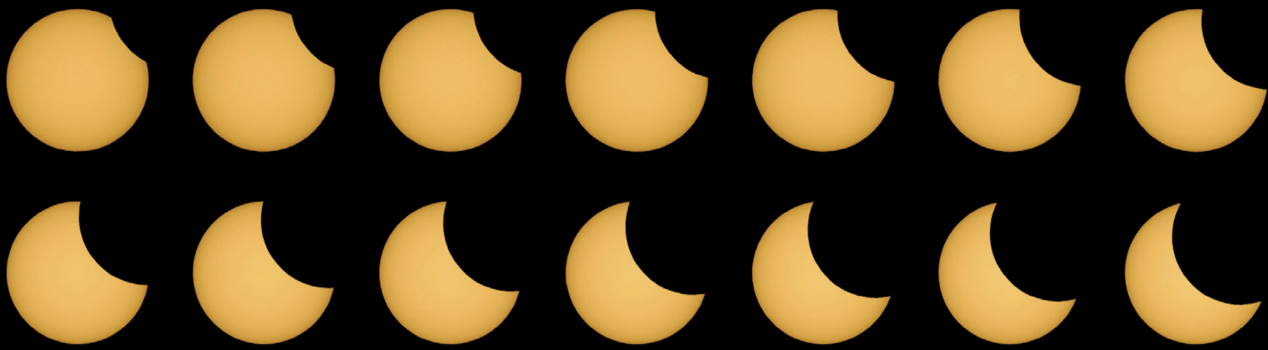
▲ **FARAWAY GALAXY** As with the open cluster M52, viewers might expect to see M31 appear in the eyepiece of a telescope like it does in the image above. When they remark that all they're seeing is a fuzzy smudge, remind them that Andromeda "weighs" as much as 400 billion Suns and lies at a whopping 2.5 million light-years from Earth. When light left the galaxy, the first *Homo* species, *Homo habilis*, appeared in East Africa along with Olduwan tools from the Olduvai Gorge.

Autumn Outreach Targets

Object	Designation	Type	Mag(v)	Size/Sep	RA	Dec.
Double Double	Epsilon Lyrae	Multiple star	4.7, 4.6	209″	$18^h 44.3^m$	+39° 40′
Epsilon[1] Lyrae		Double star	5.1, 6.1	2.3″	$18^h 44.3^m$	+39° 40′
Epsilon[2] Lyrae		Double star	5.2, 5.4	2.4″	$18^h 44.4^m$	+39° 37′
Albireo	Beta Cygni	Double star	3.2, 4.7	35″	$19^h 30.7^m$	+27° 58′
M57	NGC 6720	Planetary nebula	8.8	76″	$18^h 53.6^m$	+33° 02′
M15	NGC 7078	Globular cluster	6.3	18′	$21^h 30.0^m$	+12° 10′
M2	NGC 7089	Globular cluster	6.6	16′	$21^h 33.4^m$	–00° 49′
M52	NGC 7654	Open cluster	6.9	16′	$23^h 24.8^m$	+61° 36′
M31	NGC 224	Galaxy	3.4	190.5′ × 61.7′	$00^h 42.5^m$	+41° 15′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

SEAN WALKER / S&T



The Great Annular Eclipse of 2023

This month's alignment of the Sun and the Moon is more than just a warm-up for totality next spring.

FRED ESPENAK

On Saturday, October 14th, an annular eclipse of the Sun will be visible from parts of the western United States, Mexico, and Central and South America. Most of the rest of North and South America will experience a partial event. But to borrow a phrase from standup comedian Rodney Dangerfield, annular eclipses of the Sun "don't get no respect!" This is especially true when compared to total solar eclipses, like the one coming in April next year (*S&T:* Apr. 2023, p. 26).

Viewing Annularity

During an annular eclipse, the Moon is too far from Earth for its disk to completely obscure the Sun. In many respects, an annular is simply a special kind of partial eclipse. Although the Moon covers up to 91% of the solar disk during October's event, the Sun remains blindingly bright and unsafe to view directly. You must always use a solar filter throughout the *entire* eclipse. The so-called ring of fire during annularity can be enjoyed simply with an inexpensive pair of eclipse glasses, but if you plan to also use binoculars, a telescope, or a camera, be sure that a safe solar filter is fitted to the front end of the optics.

The projection method is another great way to view the Moon's progress as it advances across the Sun. Look for the patterns of sunlight beneath any shade tree — the small gaps between the leaves act like pinhole cameras to project hundreds of tiny crescents on the ground. You can even interlace your fingers and see the effect.

The most rewarding locations to view the eclipse lie along the 184- to 245-kilometer-wide (115- to 152-mile-wide) path of annularity. Within this zone, the Moon's disk will appear as a black orb completely ringed by the Sun's brilliant outline. A thin *annulus* (Latin for ring) of the solar disk will be visible for up to 5¼ minutes. From within the U.S., the eclipse path traverses nine states: Oregon, California, Idaho, Nevada, Utah, Colorado, Arizona, New Mexico, and Texas. Annularity also crosses parts of Mexico, Central America, and the northern portion of South America. Let's have a look at the local circumstances and weather prospects for several of these locations.

◀ **2005 RING OF FIRE** This sequence of images portrays the annular solar eclipse of October 3, 2005, as seen from Carrascosa del Campo, Spain. The 2023 annular eclipse is a member of the same Saros family (Solar Saros 134) as the 2005 event, with the Sun and Moon at similar distances from Earth. As a result, the annular phases of the two eclipses share a strong resemblance.

North Pacific, Oregon, and Nevada

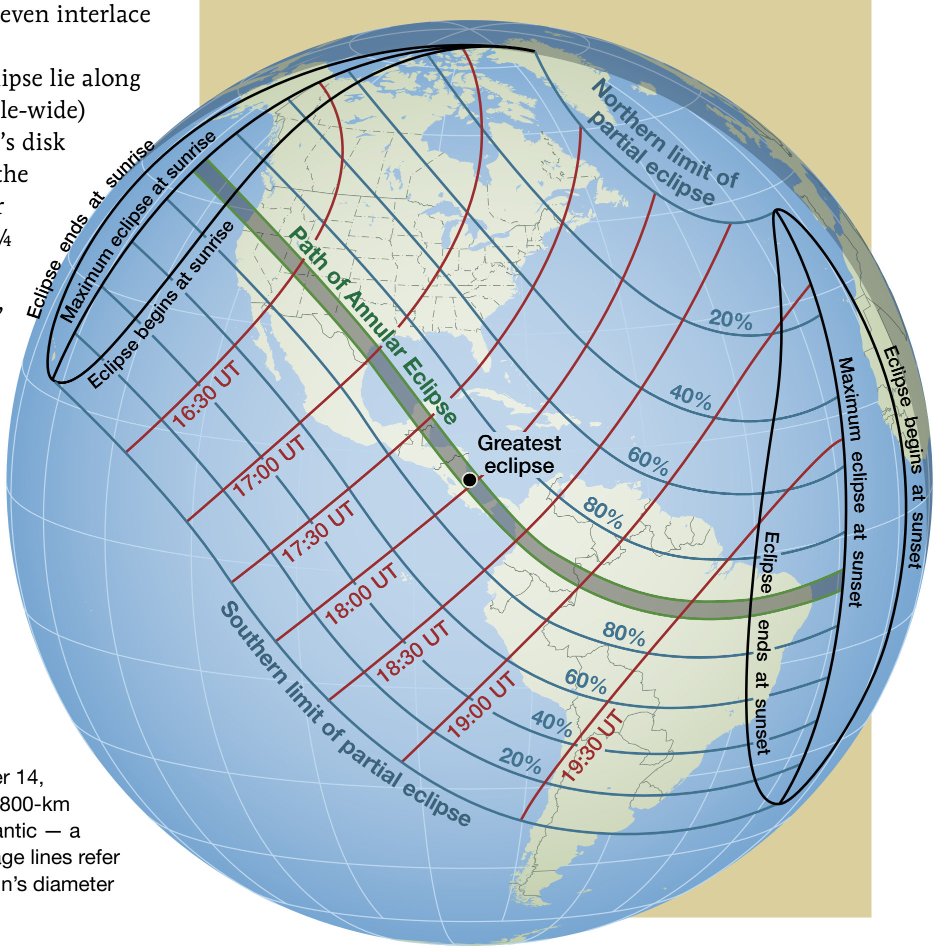
The path of the Moon's antumbral shadow first touches down on Earth's surface at 16:10 UT in the North Pacific, about 1,360 km south of Anchorage, Alaska. Along the sunrise terminator, the maximum duration of annularity is 4 minutes 14 seconds, as seen from the center of the 245-kilometer-wide path.

First landfall occurs 6 minutes later at 16:16 UT (09:16 PDT) as the shadow sweeps southeast and intercepts the Pacific Coast of Oregon, just a little south of where 2017's

Eclipse-Planning Essentials

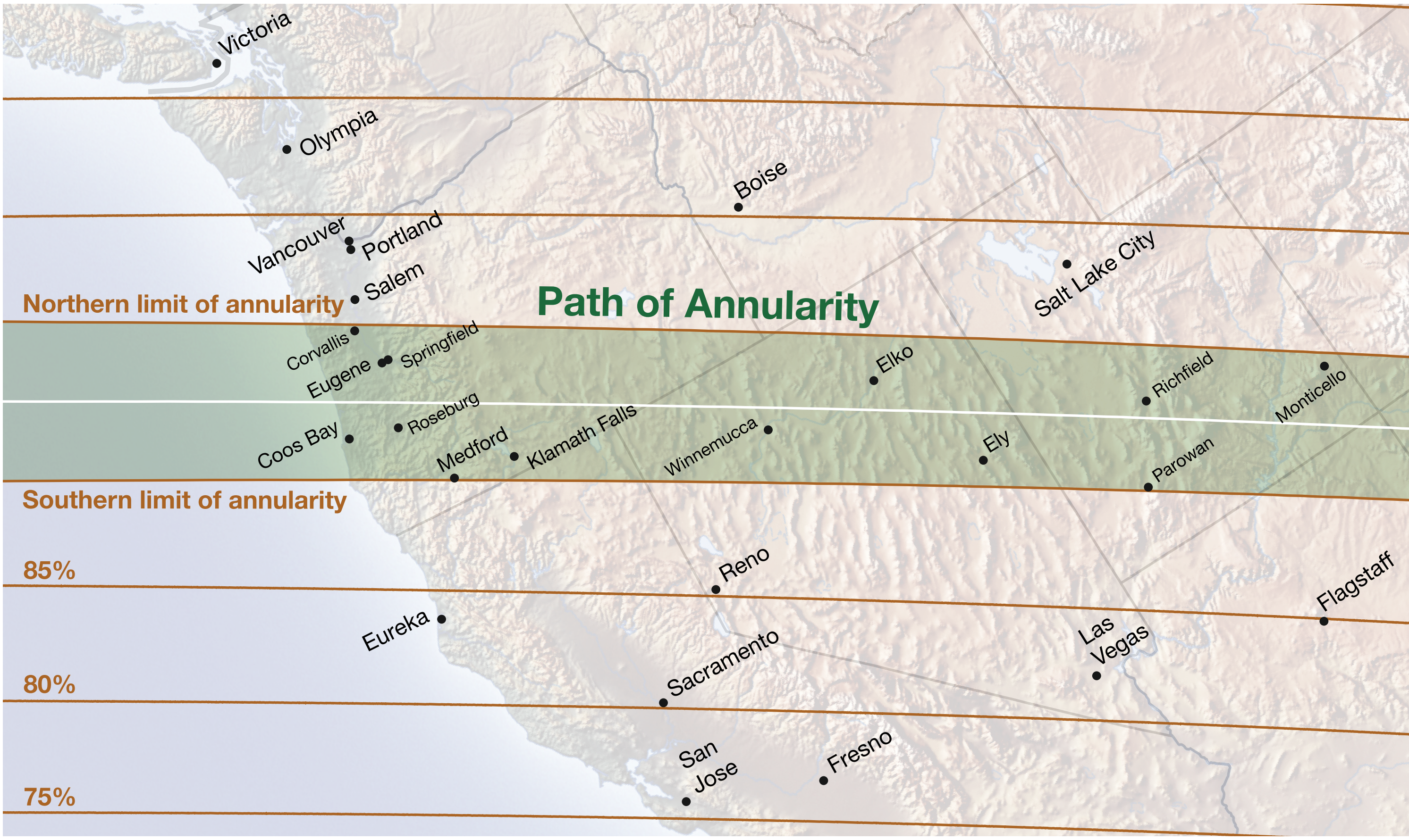
Author Fred Espenak has published *Road Atlas for the Annular Solar Eclipse of 2023*, a book of detailed roadmaps covering the entire path across the U.S., Mexico, and Central and South America. For details visit **eclipsewise.com/pubs/Atlas2023.html.**

Fred and Pat Espenak have written a family-friendly guide to the 2023 annular and 2024 total eclipses. *Get Eclipsed* explains why eclipses happen and includes fun facts and information on how to safely view these events. The 50-page booklet includes two pairs of eclipse glasses. More information can be found at **eclipsewise.com/pubs/GetEclipsed24.html**.



▶ **FROM THE PACIFIC TO THE ATLANTIC** On October 14, 2023, the Moon's antumbral shadow travels along a 13,800-km (8,600-mi) track that extends from the Pacific to the Atlantic — a journey that lasts 3 hours and 34 minutes. The percentage lines refer to the eclipse magnitude, which is the fraction of the Sun's diameter covered by the Moon.

S&T ILLUSTRATION, SOURCE: FRED ESPENAK



▲ **ANTUMBRAL ALLEY** The annular eclipse path traverses nine American states from Oregon to Texas, where the Moon's antumbral shadow leaves the U.S. and passes over the Gulf of Mexico before making landfall once again in Mexico's Yucatán Peninsula. The percentage lines refer to eclipse obscuration, which is the fraction of the Sun's area covered by the Moon. Only locations within the eclipse path (colored green) will witness annularity. (Map courtesty of Michael Zeiler, **GreatAmericanEclipse.com**.)

memorable total eclipse came ashore. At Oregon Dunes National Recreational Area the Sun stands 17° above the eastern horizon and annularity lasts $4^m\ 34^s$. Unfortunately, the weather along the coast this October is forecast to be much less friendly than it was in August 2017. Twenty years of satellite observations show that October cloud amounts average 60% to 70% along the Oregon coast, and this holds as far inland as the Cascade Range. Cloudy skies are particularly frequent in the Willamette Valley, a location that was a crowd favorite in 2017.

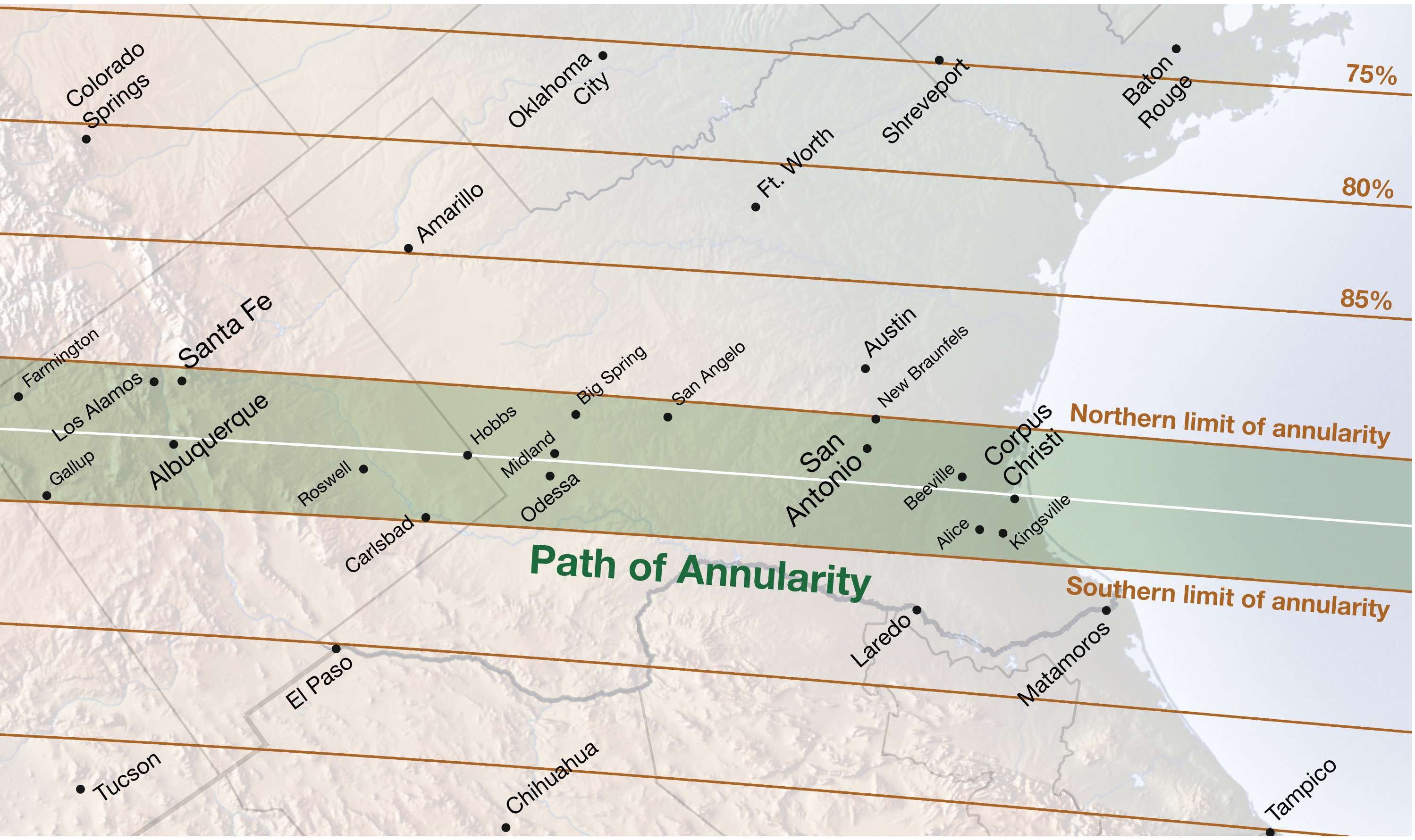
Traveling with a supersonic velocity of 9,300 km/h (more than seven times the speed of sound), the antumbra's path is 221 km wide as the shadow races across Oregon. Eugene's population of 175,000 makes it the third-largest city in the state. Although it lies 62 km north of the central line, its citizens can witness an annular phase lasting $3^m\ 54^s$. This is a consolation prize since Eugene was just outside the path of totality in 2017.

Other Oregon cities in the path include Corvallis, Roseburg, Coos Bay, Medford, and Klamath Falls. Crossing the Cascade Range, the eclipse track includes Crater Lake National Park, where the duration of annularity is $4^m\ 32^s$.

Fortunately, cloud cover declines quickly along the eclipse path. As the graph presented on page 39 shows, average cloudiness drops by about 20% from what it was at the start of the eclipse, into the mid-40% range, as the shadow crosses from Crater Lake to the Nevada-California border. However, the central line may not be the best place to be. Cloud cover varies across the width of the track, and the most promising conditions lie on the south side, particularly near Klamath Falls and Chiloquin.

The Moon's shadow next enters northeastern California and northern Nevada while barely clipping the southwestern corner of Idaho. California's Lava Beds National Monument (50 km south-southeast of Klamath Falls, Oregon) straddles the path's southern limit, but locations along the Monument's northern border still receive 1 minute of annularity.

Much of northern Nevada has a low population density. Elko (population 21,000), the largest city in the path located 45 km north of the central line, will experience $4^m\ 19^s$ of annularity, while Ely (population 4,000), in eastern Nevada, will witness $3^m\ 40^s$ of ring of fire. Just before crossing the Nevada-Utah state line at 9:26 PDT, the antumbra encounters Great Basin National Park (60km southeast of Ely), where annularity persists for $3^m\ 55^s$.



Utah and New Mexico

The eclipse track next runs diagonally across the southwestern half of Utah. At this point, the shadow's speed is 5,600 km/h. Richfield (population 8,200) is the largest city in southern-central Utah and lies 25 km north of the central line, where the duration of annularity is 4^m 37^s. Salt Lake City, the state's capital, is 120 km north of the path — its 200,500 residents will witness a deep partial eclipse with a *magnitude* (the fraction of the Sun's diameter covered by the Moon) of 0.92. Fortunately, three of Utah's national parks (Bryce Canyon, Capitol Reef, and Canyonlands) straddle the eclipse path, as do several national monuments (Bears Ears, Grand Staircase-Escalante, Hovenweep, Natural Bridges, and Rainbow Bridge) as well as Glen Canyon National Recreation Area.

As the 204-kilometer-wide track exits Utah at 10:32 MDT, it crosses the Southwest's Four Corners region, where the borders of Utah, Arizona, Colorado, and New Mexico meet. The picturesque sandstone buttes of Monument Valley Navajo Tribal Park along the Utah-Arizona border receive 4^m 38^s of annularity. Visitors to Colorado's Mesa Verde National Park can expect an annular phase lasting 2^m 44^s.

Across the Great Basin of Nevada and Utah, central-line cloudiness declines a further 15%, falling to the mid-20% range at the Colorado border. Here again, the south side of the track offers the best climatology, from Unionville to Eureka in Nevada, and onward to Beaver and Bryce Canyon in Utah.

Bryce Canyon National Park in Utah marks the start of the very best weather prospects, and sunshine dominates from there across Monument Valley, Four Corners National Park, Albuquerque, and Roswell. Monthly cloud cover drops below 30% — the lowest along the whole eclipse track. There is not much to choose between one site or another across this part of the American Southwest.

The eclipse path runs diagonally across New Mexico from its northwestern to its southeastern corners and encompasses nearly half the state. As a result, numerous national parks and monuments lie inside the eclipse track, including Aztec Ruins, Chaco Canyon, Bandelier, Valles Caldera, Kasha-Katuwe Tent Rocks, Petroglyph, and Pecos. New Mexico's largest city, Albuquerque (population 562,000), is just south of the central line and receives 4^m 50^s of annularity at 10:37 MDT. By coincidence, the eclipse occurs in the final days of the annual Albuquerque Balloon Fiesta, a major tourist attraction in the area.

Big, persistent weather systems are uncommon in New Mexico in October, but their passage farther north often sends weakening cold fronts into the state. They are most likely to affect the areas southwest of Albuquerque, toward the Texas border. Jet-stream winds flowing across the Mexican border bring high-level cirrus clouds, but these are usually too thin to completely hide the eclipse.

Texas

Now 196 km wide, the annular track crosses the New Mexico-Texas border and enters the Lone Star State at 11:44 CDT. The shadow's ground speed has dropped to 3,500 km/h. Crossing Interstate 20 between Odessa and Midland, the central line duration is $4^m\ 56^s$, and the Sun's altitude is 42°.

San Antonio (population 1.4 million) is not only the second-largest city in Texas, but it's the largest American city along the eclipse path. Mid-annularity occurs at 11:54 CDT and lasts $4^m\ 23^s$. October's annular eclipse can be seen as a warmup since San Antonio also lies on the southern limit of next April's total eclipse. As the path reaches the Gulf Coast, Corpus Christi (population 318,000) lies on the central line, where annularity lasts $5^m\ 02^s$.

The favorable cloud climatology of the Midwest extends into Texas as far as Midland and Odessa, but as the shadow track moves toward the Gulf of Mexico, the frequency of cloudy skies increases sharply. The greatest cloud cover is along the coast, exceeding 60% toward both the northern and southern limits of annularity; it's a little less along the central line.

From San Antonio southward, much of the October morning cloud forms in a moist flow from the Gulf of Mexico that turns into small cumulus buildups as the Sun warms the ground. These convective clouds may disappear with eclipse cooling or turn into a shallow stratocumulus layer. There are usually many gaps in this low-level cloud, so eclipse-seekers along the track southeast of Odessa should be prepared to move to another location, even just a short distance.

Other weather systems also pose problems for Texas. Cold fronts moving southward typically slow and come to a halt

Weather Watching

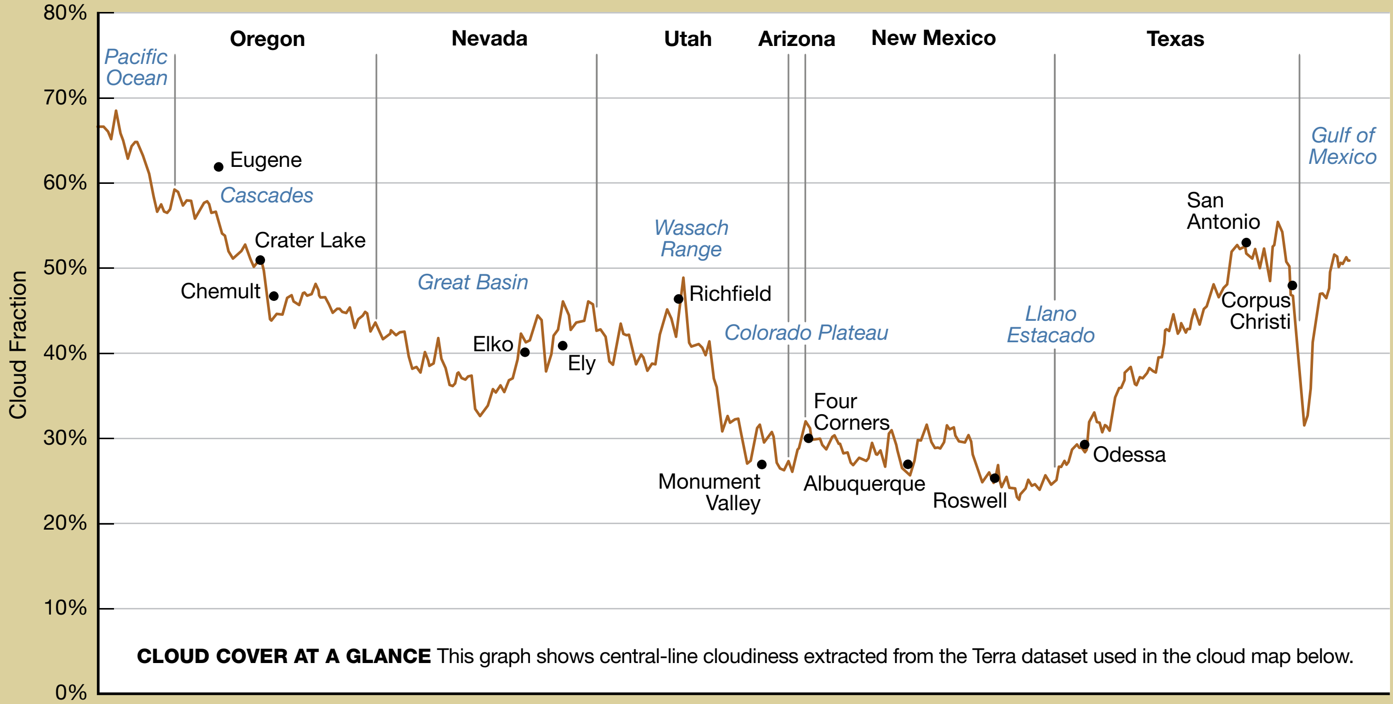
From wherever you choose to view this annular eclipse, a weather forecast — particularly a cloud forecast — could be the key to success. The weather forecasts on TV and the internet may be all you need, but studying computer models in the days before and a glance at the satellite images on eclipse morning may prove critical.

The College of DuPage's NeXt Generation Weather Lab (**weather.cod.edu**) is well-known among storm chasers for its high-resolution satellite images and its collection of numerical weather charts from Canada and the United States. Travelers to last April's total eclipse found Windy (**windy.com**) and Meteologix (**meteologix.com**) useful since both offer a global perspective and access to some European forecast models. For a selection of numerical forecasts for a single site, try SpotWeather (**spotwx.com**).

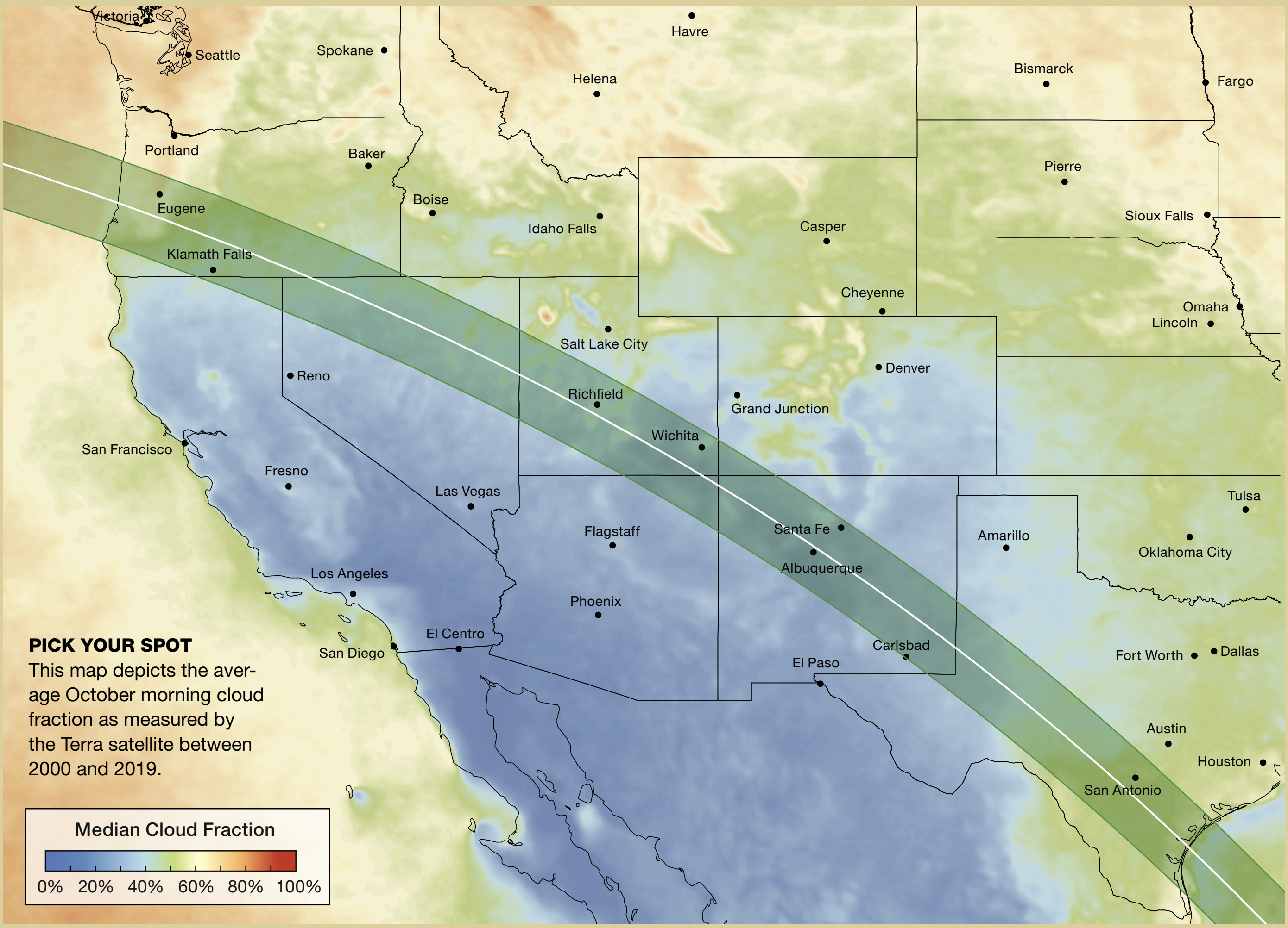
It's best to settle on just two or three forecast models to avoid getting bogged down with too many predictions. And while some sources offer forecasts as much as 15 days before the event, these aren't reliable until much closer to eclipse day. When you see two or three models converging (three days ahead or thereabouts) and when a single model begins to make the same forecast after each update, you can start to make your final plans.

SMITTEN WITH THE SIGHTS The photo above captures a view of the Mittens at Monument Valley, located on the Arizona-Utah border. From here, the Sun will be 32° high at maximum eclipse, allowing some interesting photo opportunities among the rock formations.

JAY ANDERSON



CLOUD COVER AT A GLANCE This graph shows central-line cloudiness extracted from the Terra dataset used in the cloud map below.



PICK YOUR SPOT
This map depicts the average October morning cloud fraction as measured by the Terra satellite between 2000 and 2019.

JAY ANDERSON / DATA SOURCE: NASA (2)

▶ **BEFORE AND AFTER** The moments immediately before (top) and after annularity (bottom) as recorded during the solar eclipse of October 3, 2005. During a total eclipse, the new Moon passes directly in front of the Sun. An annular eclipse occurs when the disk of the Moon is too small to completely cover the face of the Sun.

FRED ESPENAK

when they meet the Gulf Coast, leaving a band of cloud across the shadow path that can later redevelop into a larger disturbance. Thunderstorms, sometimes with severe weather, can form overnight along the coast and persist past eclipse time, throwing up large and dense cloud shields. However, 23 years of satellite images show that sunny spots existed within 50 miles of San Antonio on two-thirds of the past October 14ths. The challenge is to find the gaps in the cloud cover at short notice.

Mexico and South

The antumbral shadow takes 25 minutes to cross 1,000 km of open water in the Caribbean before it encounters the west coast of the Yucatán Peninsula at 13:23 EST. The eclipse track crosses parts of three countries in the Yucatán: Mexico, Guatemala, and Belize. Belize City (population 60,000) is near the central line and experiences an annular phase lasting 5^m 11^s.

In the Yucatán cloudy days are the rule according to satellite data. But here again, the type of cloud makes all the difference — they're mostly small cumulus clouds that will likely dissipate with the approaching eclipse. Because of cool waters offshore, locations near the coast have a more promising climatology than those inland. That's why residents of Campeche, Mexico, would have been able to view an eclipse on about 80% of the past 23 October 14ths. This October, the eclipse is high in the sky over the Yucatán, and the bright solar ring should be relatively easy to follow in a thin overcast.

The track next crosses Honduras and Nicaragua before slipping back into the Caribbean. The instant of *greatest eclipse*, when the axis of the Moon's shadow passes closest to Earth's center, occurs in the Caribbean at 12:59:29 EDT (17:59:29 UT). The duration is 5^m 17^s, the path width is 184 km, and the *obscuration* (the fractional area of the Sun's disk covered by the Moon) is 0.905. The ground speed has slowed down to a relatively leisurely 2,200 km/h.

After traversing western Panama, the eclipse track enters Colombia as it gradually curves east toward Brazil — the final country within the path. As the shadow reaches Brazil's Atlantic Coast, Natal (population 890,000) residents witness a 3^m 35^s annular phase in the late afternoon (16:46 Brasilia Time), with the Sun just 6° above the horizon. Four minutes later (at 19:50 UT), the antumbra leaves Earth and the annular eclipse ends.

Throughout this part of the annular eclipse track, clouds are primarily convective, blossoming with large storms that combine to bring an average cloudiness approaching 100%. However, there are small oases in this gloom, especially in eastern Brazil, where average cloud cover drops to 30%, making this small part of the track one of the most promising for viewing the event.

Some Final Notes

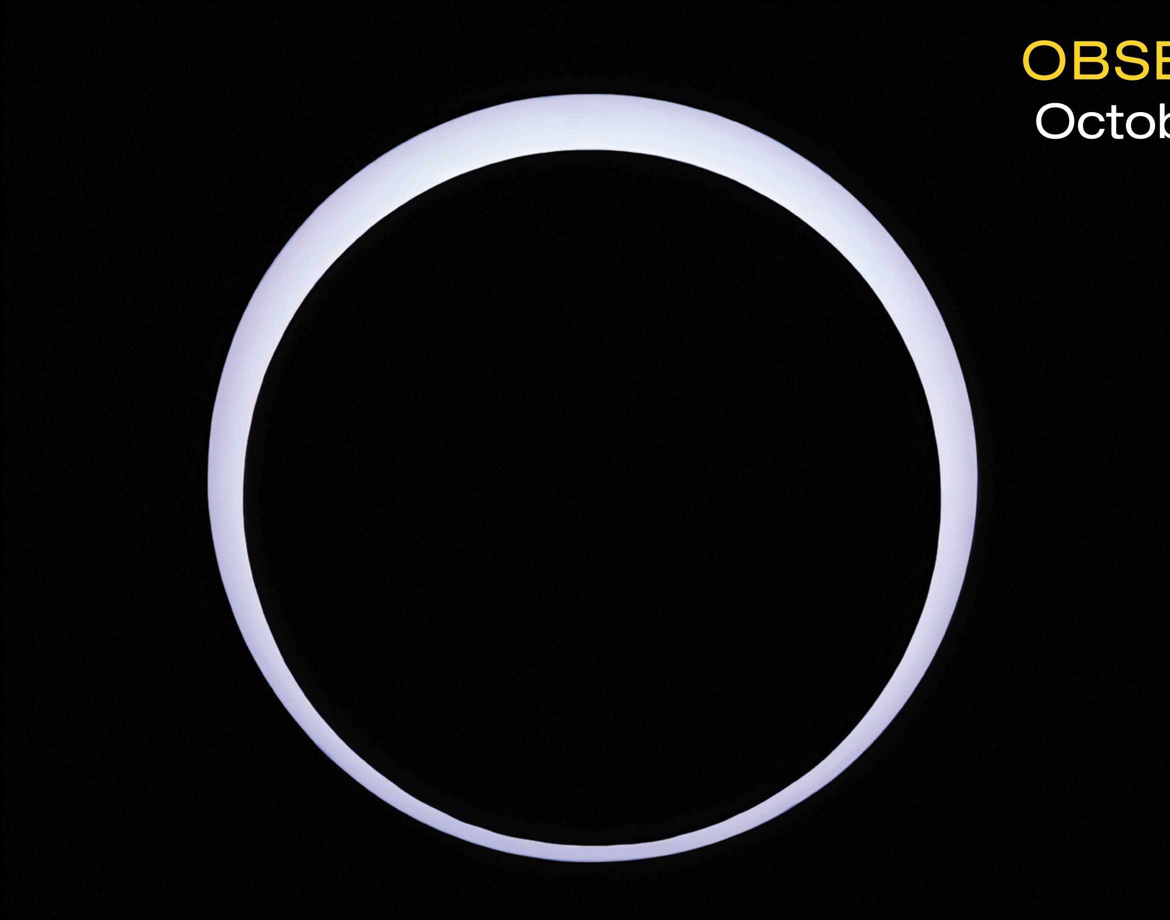
Over the course of 3 hours and 34 minutes, the Moon's antumbral shadow traverses 13,800 kilometers and covers 0.57% of Earth's surface area. The American Southwest is easily one of the most scenic areas in the U.S. The cooler, post-summer temperatures, coupled with frequently clear skies, make the area particularly attractive for both tourists and eclipse chasers alike. And amateur astronomers will also revel in the incredibly dark night skies the region has to offer.

Even if you don't travel to the path of annularity, most viewers will see an intriguing partial eclipse. Looking up from Miami, Florida, at mid-eclipse (using safe viewing techniques, of course), you'll see 67% of the solar disk covered by the Moon. From Los Angeles, California, it will be 78%. The partially eclipsed Sun will be worth viewing even from such widely separated locations as Vancouver, British Columbia (82%), Minneapolis, Minnesota (57%), and New York City (35%).

You may see this annular eclipse as just the opening act to totality in 2024, but the appearance of a perfectly symmetric annular ring is wonderfully beautiful in its own way. The annular eclipse also offers an excellent opportunity to witness Baily's Beads — glimmers of sunlight shining through deep lunar valleys. After all, Francis Baily first described this phenomenon while observing an annular eclipse in 1836.

■ **FRED ESPENAK**, a.k.a. Mr. Eclipse, is world-renowned for his eclipse predictions and photography. **JAY ANDERSON** is a Canadian meteorologist who has been dispensing advice to eclipse chasers since 1979. His forecasts can be found at **eclipsophile.com**.

OBSERVING
October 2023



1 **EVENING:** Face east-northeast to see the waning gibbous Moon some 2° upper left of Jupiter as they rise together. Page 46 has more details on this and other events listed here.

2 **EVENING:** The Moon and the Pleiades, around 1½° apart, climb above the east-northeastern horizon. Binoculars will help reveal the dimmer cluster lights in the Moon's dazzle.

6 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:53 p.m. PDT (see page 50).

7 **MORNING:** High in the east, the waning crescent Moon is in Gemini around 1½° lower right of Castor; Pollux twinkles above the duo.

8 **MORNING:** The Moon visits Cancer where it gleams some 3½° upper left of the Beehive Cluster (M44).

9 **DAWN:** Venus, the Morning Star, blazes less than 2½° lower right of Regulus, Leo's brightest star.

9 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:42 p.m. EDT (8:42 p.m. PDT).

10 **DAWN:** The thin lunar crescent is now in Leo where it forms a line with Venus and Regulus. Catch this sight before the Sun rises.

12 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:30 p.m. EDT.

14 **NEW MOON (1:55 PM EDT):** An annular solar eclipse will be visible along a narrow path that sweeps from the Northwest of the United States through Texas and beyond. Much of the rest of the Americas will see a partial eclipse. See page 34 for the full story.

18 **DUSK:** The waxing crescent Moon and the Scorpion's smoldering heart, Antares, sink toward the southwestern horizon with less than 5° between them.

21–22 **ALL NIGHT:** The Orionid meteor shower peaks. The first-quarter Moon sets during the evening of the 21st and won't interfere with viewing.

23 **EVENING:** The waxing gibbous Moon hangs some 5° below Saturn. Look to the south-southwest to take in this view.

28 **FULL MOON (4:24 PM EDT)** The final phases of a partial lunar eclipse will be visible in northeastern North America and much of South America, while all of Europe and most of Africa and Asia will witness the entire event.

28 **EVE:** The full Moon hangs a bit more than 2½° above Jupiter high in the southeast.

29 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:23 p.m. PDT.
— DIANA HANNIKAINEN

▲ The Moon and the Sun will cross paths on October 14th, which will result in an annular eclipse for many across the Americas. DENNIS DI CICCO

OCTOBER 2023 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

LAST QUARTER
October 6
13:48 UT

NEW MOON
October 14
17:55 UT

FIRST QUARTER
October 22
03:29 UT

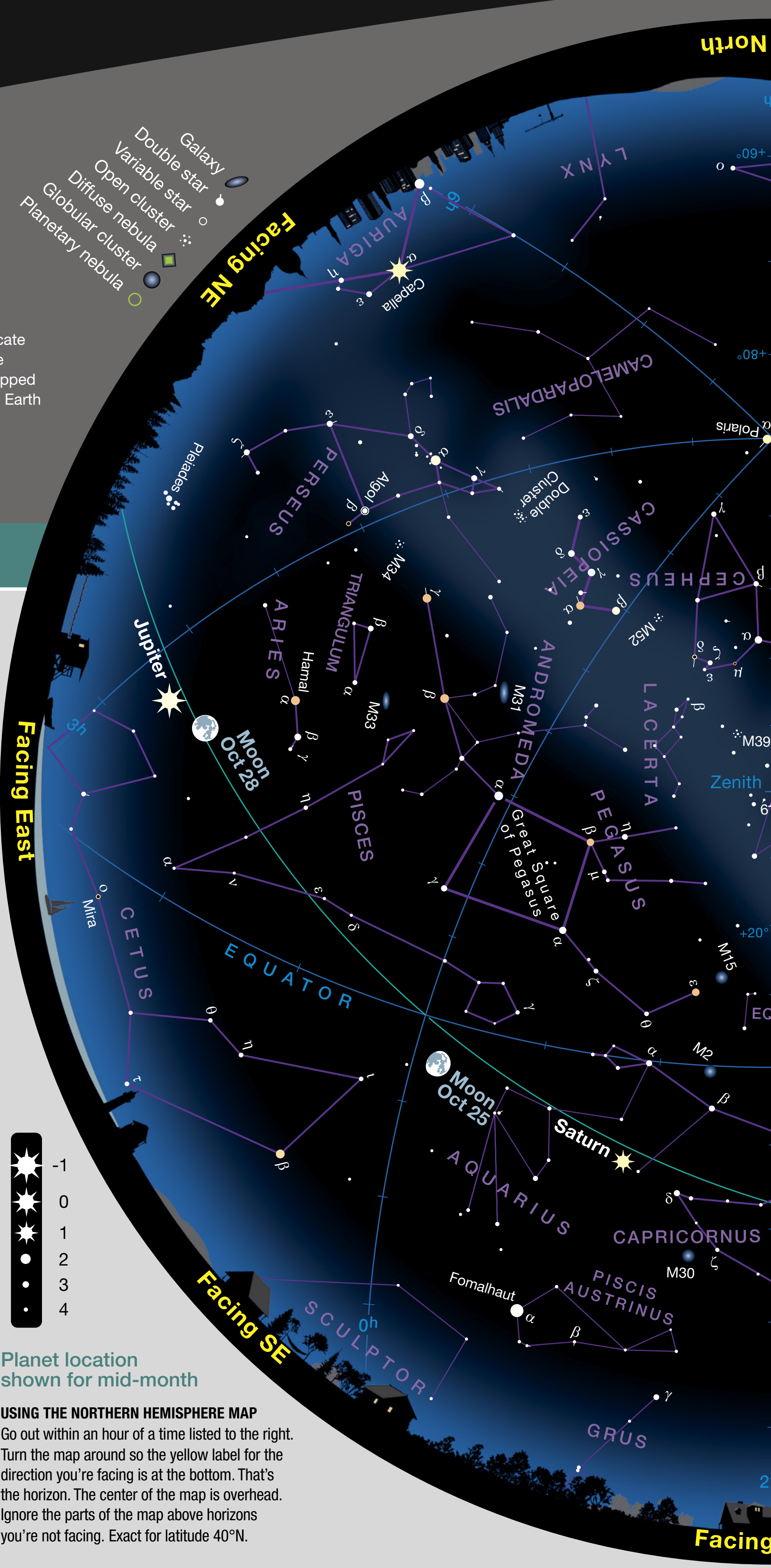
FULL MOON
October 28
20:24 UT

DISTANCES

Apogee	October 10, 04^h UT
405,425 km	Diameter 29′ 28″
Perigee	October 26, 03^h UT
364,873 km	Diameter 32′ 45″

FAVORABLE LIBRATIONS

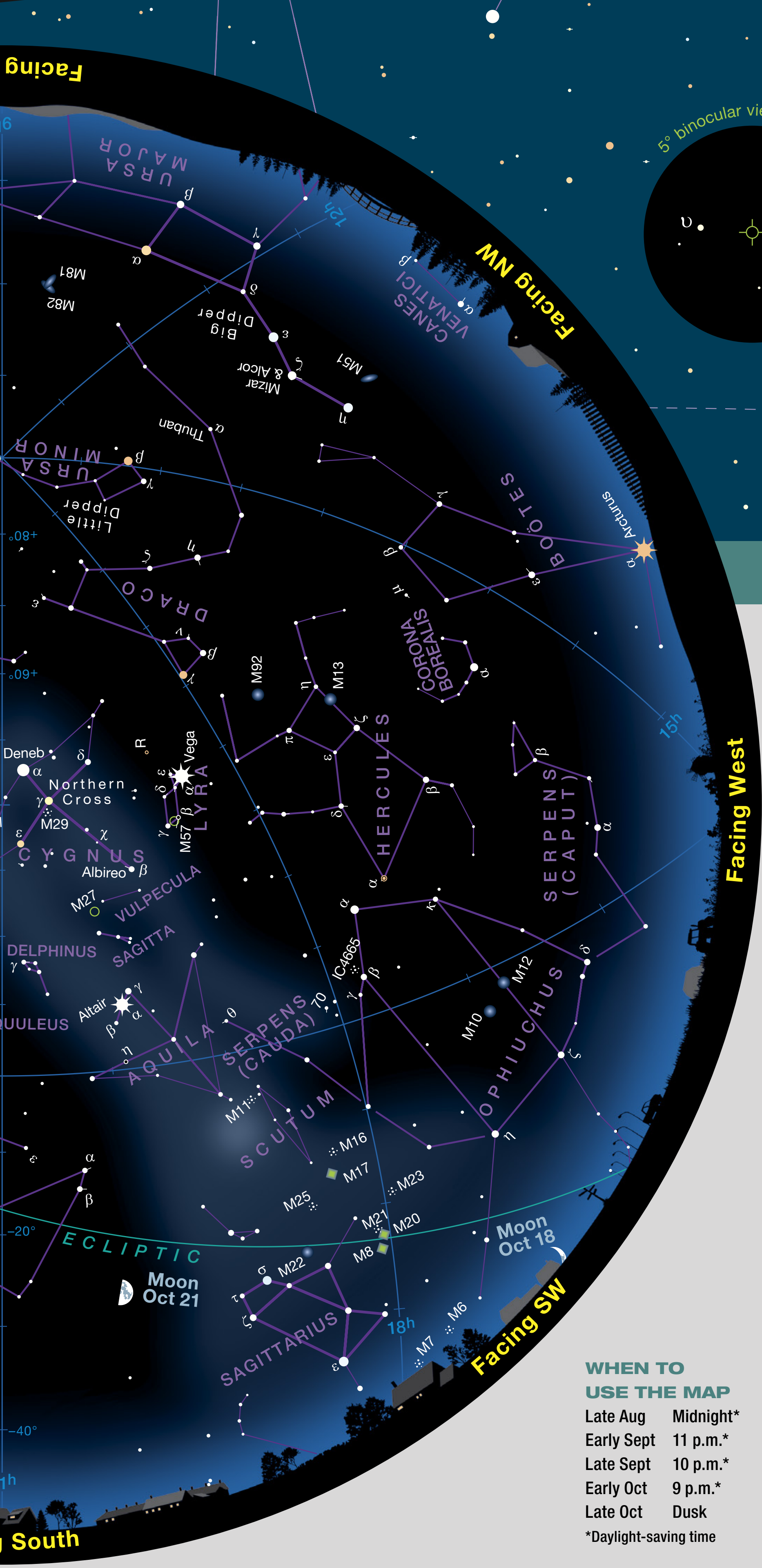
• Petermann Crater	October 26
• Lacus Spei	October 27
• Neper Crater	October 28
• Gibbs Crater	October 29

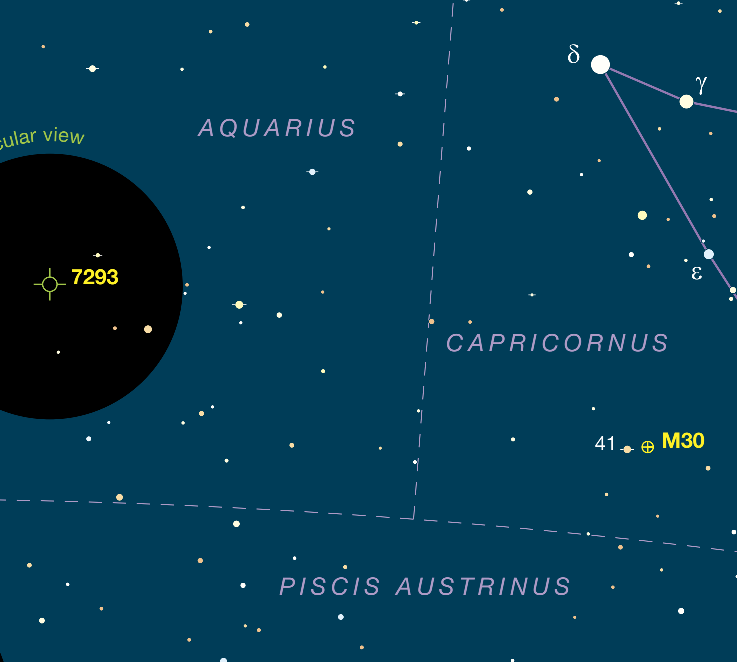


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





WHEN TO USE THE MAP

Late Aug	Midnight*
Early Sept	11 p.m.*
Late Sept	10 p.m.*
Early Oct	9 p.m.*
Late Oct	Dusk

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Hide and Seek

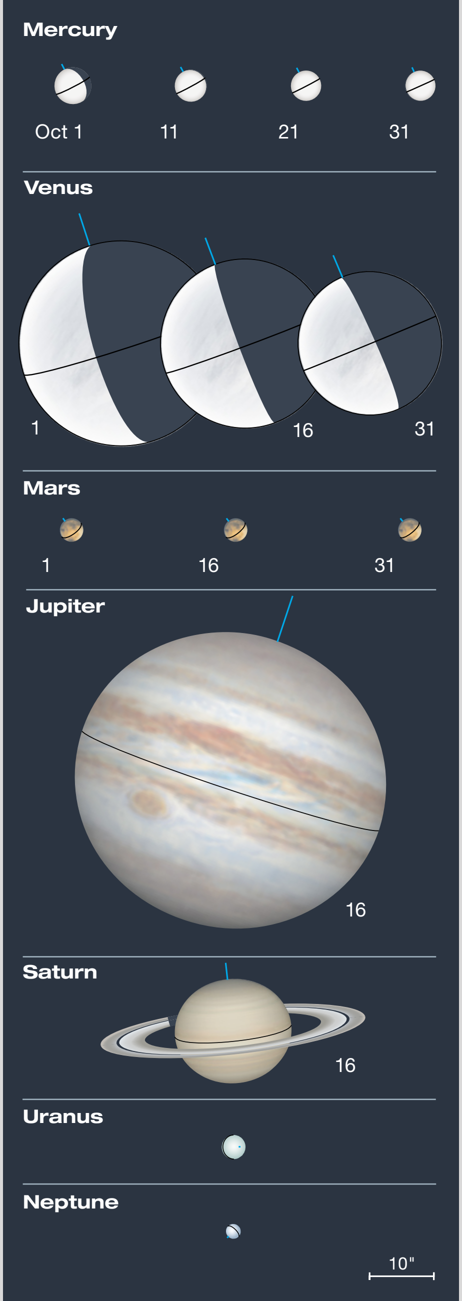
To me, one of the paradoxes of stargazing is that objects can be too *close* to see clearly if their faint light is spread out across too much sky. Hunting down these nearby objects reminds me of playing hide-and-seek with childhood friends — just because they're close doesn't mean they're easily found.

One elusive celestial neighbor is **NGC 7293**, the Helix Nebula. This alluring planetary floats in the southwestern corner of Aquarius, the Water Bearer, about 1° west of Upsilon (υ) Aquarii. The average distance to the Messier and Caldwell planetaries is about 3,000 light-years, but most recent studies put the Helix only about 600 light-years away, making it the closest planetary nebula to Earth. Various sources put the nebula's brightness between magnitude 7.3 and 7.6, but that light is spread out across 12′ — and worse, that light is distributed in the Helix's doughnut-shape perimeter. You'll need clear, dark skies, clean optics, and good dark adaptation to spot this big, close apparition. Good luck!

For an interesting comparison, hop over the border into Capricornus, the Sea Goat, to track down **M30**. Look for this 7th-magnitude globular cluster just west of 41 Capricorni, making a nearly right angle with Delta (δ) and Zeta (ζ) Capricorni (see chart at left). M30 lies about 23,000 light-years away, roughly 40 times farther than the Helix Nebula. Although the cluster has similar apparent dimensions to the Helix, it's a bit brighter. That, along with a condensed core representing the combined light of tens of thousands of stars, makes it a much easier catch. In 7×50 binoculars I struggle to see it as nonstellar, but 10×50s start to show it as an extended object.

■ **MATT WEDEL** is irritated by objects that are too big and too faint to see clearly — including most of the Milky Way's satellite galaxies.

OCTOBER 2023 OBSERVING
Planetary Almanac



▲ PLANET DISKS are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

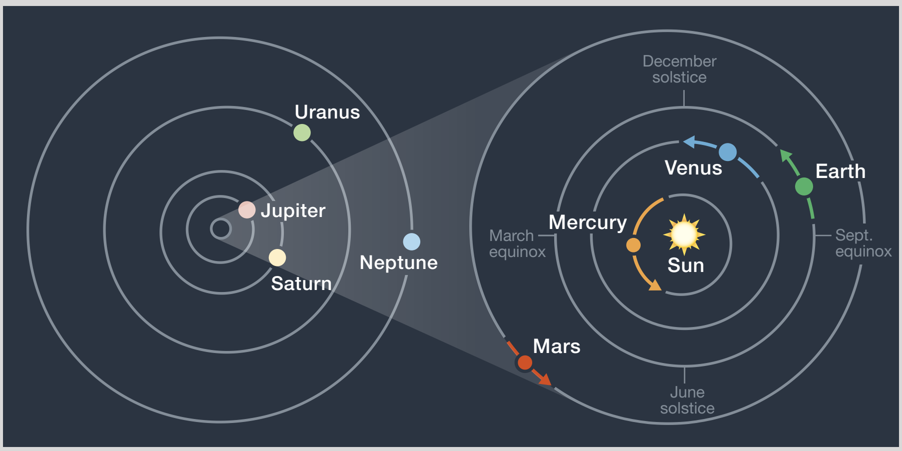
▶ ORBITS OF THE PLANETS The curved arrows show each planet's movement during October. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn to the 8th • **Venus** visible at dawn all month • **Mars** is lost in the Sun's glare this month • **Jupiter** rises around sunset and is visible all night • **Saturn** transits in the evening and sets before dawn.

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h\ 26.6^m$	–2° 52′	—	–26.8	31′ 57″	—	1.001
	31	$14^h\ 18.5^m$	–13° 50′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$11^h\ 36.5^m$	+4° 33′	15° Mo	–1.0	5.7″	81%	1.173
	11	$12^h\ 40.4^m$	–2° 34′	7° Mo	–1.3	5.0″	97%	1.347
	21	$13^h\ 43.3^m$	–9° 56′	1° Ev	—	4.7″	100%	1.424
	31	$14^h\ 44.9^m$	–16° 22′	7° Ev	–0.9	4.7″	98%	1.431
Venus	1	$9^h\ 38.4^m$	+10° 57′	44° Mo	–4.7	31.9″	36%	0.523
	11	$10^h\ 11.2^m$	+9° 28′	46° Mo	–4.6	28.0″	43%	0.597
	21	$10^h\ 47.8^m$	+7° 10′	46° Mo	–4.5	24.8″	49%	0.672
	31	$11^h\ 26.7^m$	+4° 09′	46° Mo	–4.4	22.3″	54%	0.747
Mars	1	$13^h\ 22.6^m$	–8° 18′	15° Ev	+1.7	3.7″	99%	2.541
	16	$14^h\ 00.6^m$	–12° 04′	10° Ev	+1.6	3.7″	100%	2.550
	31	$14^h\ 40.5^m$	–15° 32′	6° Ev	+1.5	3.7″	100%	2.546
Jupiter	1	$2^h\ 48.3^m$	+14° 44′	143° Mo	–2.8	47.7″	100%	4.132
	31	$2^h\ 34.6^m$	+13° 39′	176° Mo	–2.9	49.5″	100%	3.983
Saturn	1	$22^h\ 15.3^m$	–12° 44′	144° Ev	+0.6	18.6″	100%	8.937
	31	$22^h\ 11.6^m$	–13° 02′	113° Ev	+0.7	17.8″	100%	9.321
Uranus	16	$3^h\ 18.1^m$	+17° 55′	150° Mo	+5.6	3.8″	100%	18.754
Neptune	16	$23^h\ 44.5^m$	–3° 04′	153° Ev	+7.8	2.4″	100%	29.013

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org.**



A (Great) Square Deal

Autumn's most expansive asterism ropes in two constellations.

▲ **HORSING AROUND** Most of the brightest stars belonging to Pegasus, the Winged Horse, are part of the Great Square asterism, which occupies the left side of this image. However, the Square's brightest star (2.1-magnitude Alpheratz, at upper left) belongs to neighboring Andromeda.

ALAN DYER

Without doubt, the best-known autumn asterism is the Great Square of Pegasus. Yet despite its fame, it's not quite a square and its brightest star isn't even in Pegasus. Nevertheless, the Square definitely is "great" — both in size and in its many fascinating details.

Clockwise from the upper right (northwest), the Great Square comprises four stars: Beta (β) Pegasi (Scheat), Alpha (α) Pegasi (Markab), Gamma (γ) Pegasi (Algenib), and Alpha Andromedae (Alpheratz or Sirrah). Scheat is an orange-tinted, long-period variable star that ranges in brightness from magnitude 2.3 down to 2.7 and averages 2.4. Markab shines at magnitude 2.5, Algenib is the faintest at 2.8, and Alpheratz at magnitude 2.1 is the brightest. Alpheratz is one of those rare cases of a star that officially lies in one constellation but is shared with another to complete an important asterism. The other prominent example is 2nd-magnitude Beta Tauri, which holds down the southern point in the Pentagon of Auriga. Taurus and Auriga are visible in October, rising in the northeast late in the evening.

Alpheratz is the first star in a gentle arc of three similarly bright suns that (with a fainter arc, to the north) traces out the body of Andromeda, the Chained Maiden. In addition, those arcs of Andromeda also represent the rear legs of an upside-down Pegasus, the Winged Horse.

Pegasus has one more bright star, but it's so far from the Great Square that it almost seems like it could belong to some other constellation. Epsilon (ε) Pegasi is a 2.4-magnitude orange glint that's better known as Enif. It marks the Flying Horse's nose and dominates a relatively sparse area between the Great Square and 1st-magnitude Altair in Aquila. Deep-sky enthusiasts are familiar with Enif because it provides a handy jumping-off point for the lovely globular cluster M15.

All told, from Alpheratz to Enif, Pegasus stretches across a huge swath of sky, with the Great Square occupying much of this expanse. The Square is actually a rectangle and is slightly longer east-to-west than north-to-south. It marvelously extends almost exactly from the 23^h to the 0^h line of right ascension — the western and eastern sides of the Square loosely parallel those lines. You can use the two sides to locate several bright stars and identify other autumn constellations.

If you extend the west side of the Square southward about 45°, your gaze will land upon Fomalhaut, the mouth of Piscis Austrinus, the Southern Fish. Fomalhaut is the sole 1st-magnitude star in the constellations of autumn. A slightly shorter (and less accurate) line south from the Square's eastern edge leads us to Beta Ceti, the tail of Cetus, the Whale. Also known as Diphda and Deneb Kaitos, it's the constellation's brightest star. Even so, at magnitude 2.0, it's no match for Fomalhaut, which shines at magnitude 1.2.

A long line drawn northward from the eastern side of the Square brings your eye to 2.3-magnitude Beta Cassiopeiae, the westernmost star in the W of Cassiopeia. Extending the line even farther brings you to Gamma Cephei, the 3.2-magnitude peak of the roof of the little house pattern of Cepheus.

Although the Great Square is associated with autumn evenings, it's also visible in springtime at dawn. That's when it can guide you to the radiant of May's Eta Aquariid meteor shower, which features fragments of Halley's Comet. Simply extend a line diagonally southwest through the Square's two Alpha stars (Alpheratz and Markab) a distance equal to the space between the stars to land just west of the shower radiant.

Finally, the Great Square can even help you gauge the quality of your sky. On a clear, moonless night, count up the stars you see within the Square. From a suburban location you might see only two but under ideal conditions you could discern more than 30. Visit our website for a comprehensive article (and star chart) by Bob King that describes how to use the stars within the Great Square to judge sky quality. You'll find it at **https://is.gd/greatsquare**.

■ **FRED SCHAAF** enjoys sighting the dim Circlet asterism of Pisces just below the Great Square.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

The Moon Meets Jupiter . . . Twice

Good timing results in a mirrored pair of eye-catching conjunctions.

SUNDAY, OCTOBER 1

It's handy when a month begins with an eye-catching close conjunction involving the **Moon** and a bright planet. On this evening, that planet happens to be **Jupiter**, which gleams at magnitude –2.8. Why is that handy? Because the Moon returns to roughly the same place in the sky in a span of time known as a *sidereal month*, which is 27.3 days long. The important thing to note here is that a sidereal month is shorter than a calendar month. As a result, we get not one but *two* Moon–Jupiter pairings in October. (See the facing page for details on the second one.)

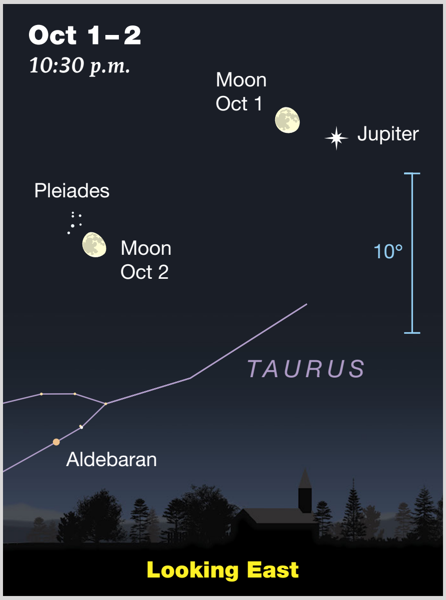
This evening, look toward the east-northeast to catch a waning gibbous Moon (two days past full) and Jupiter rising just 2° apart — the Moon will pop up about 10 minutes before the planet. The gap between the twosome will more than double as they arc across the sky together tonight, thanks to the Moon's eastward motion along the ecliptic. That's why the earlier you look, the more spectacular the sight will be.

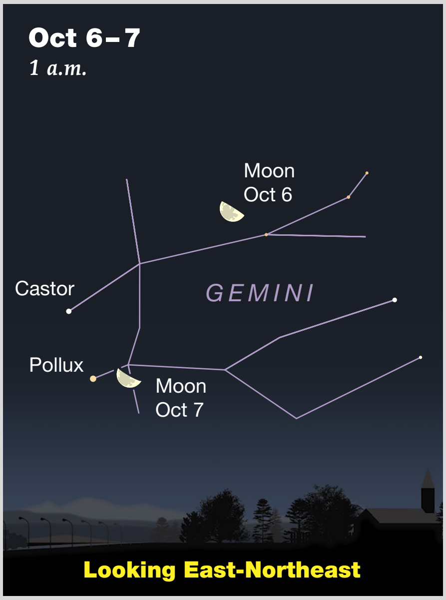
MONDAY, OCTOBER 2

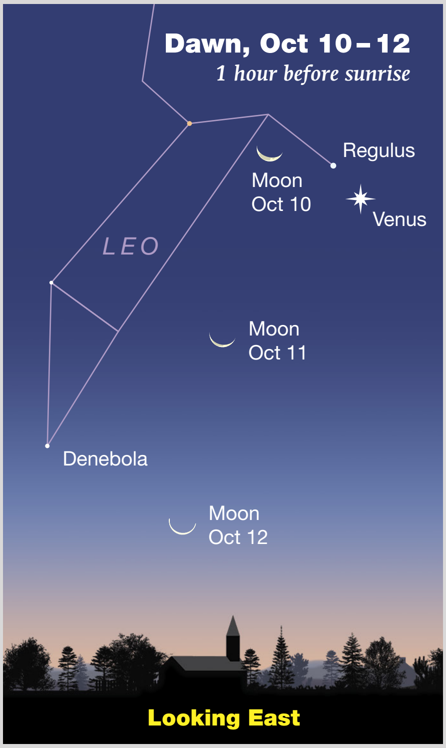
A little more than 24 hours after its encounter with Jupiter, the **Moon** pairs up with the **Pleiades**. This conjunction won't be as interesting as the previous night's, however. The lunar disk remains very bright, and the cluster's stars have a tough time competing against the Moon's glare. That's why you'll want to grab your binoculars before heading outdoors — the extra light grasp and magnification that binos offer go a long way toward making the event viewable. Thankfully, the objects are close together: Just 2° separates the Moon from 2.9-magnitude Alcyone, the brightest Pleiad. That's close enough that the entire cluster and the Moon comfortably fit together in the field of view of 10×50s.

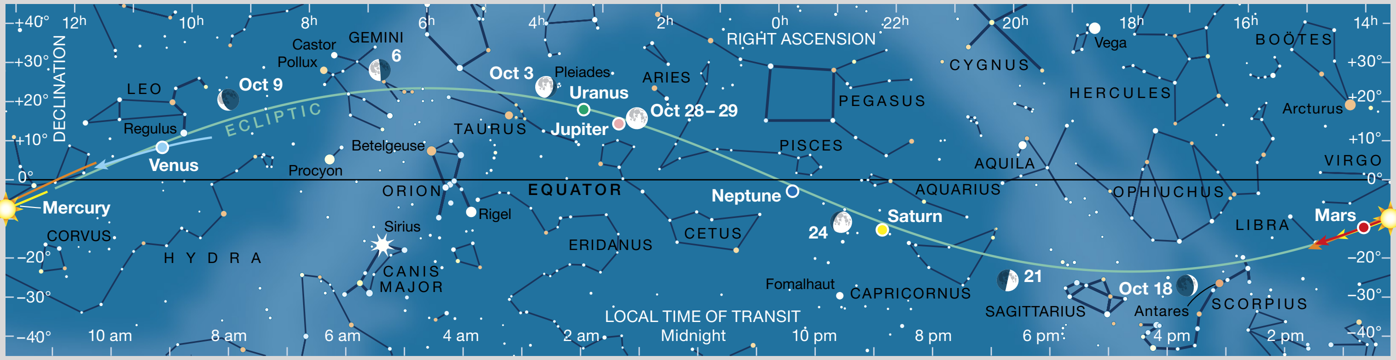
As the night of the 2nd transitions into the morning of the 3rd, the lunar disk shifts from lying under the Pleiades to sitting left of the cluster, but all the while remaining close enough to fit within a single binocular field of view.

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.







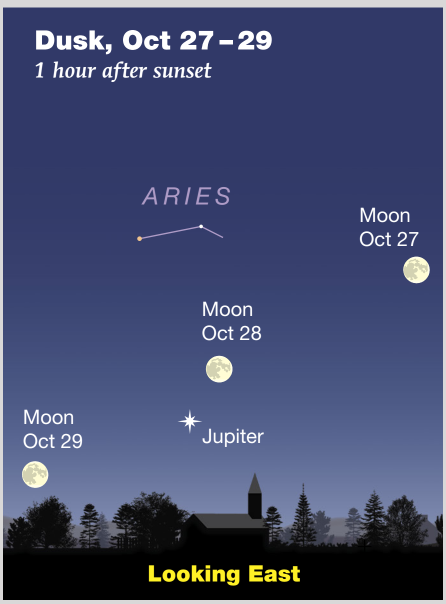


▲ The Sun and planets are positioned for mid-October; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

SATURDAY, OCTOBER 7

Next on the lunar agenda: a meeting in Gemini with **Castor** and **Pollux**, the constellation's brightest stars. You can think of this as being two events in one. As the waning crescent **Moon** rises (shortly after midnight on the morning of October 7th), it's a bit more than 2½° right of Pollux. Along with nearby Castor, the trio form an attractive right-triangle.

The second event is for early risers because it takes place just as morning twilight begins to brighten the sky. By then the triangle has gotten bent out of shape, and the gap between the Moon and Pollux has shrunk to 1½°. For observers on the West Coast, darkness will linger just long enough for you to be able to see the Moon form a perfectly straight 6½°-long line with the two bright Gemini stars as the configuration approaches the zenith. The alignment is most perfect shortly after 5 a.m. PDT.



TUESDAY, OCTOBER 10

This morning features what is arguably October's most arresting conjunction, and once again the **Moon** is a key player. This time it shares the stage with **Regulus** — the brightest star in Leo, the Lion — and brilliant **Venus**, the reigning Morning Star. The planet is nearing the climax of its current morning apparition as it approaches its greatest elongation (46° west of the Sun), which occurs on the 23rd. Of course, Venus will linger at dawn far beyond that date. It'll remain visible throughout winter and into spring, when it finally succumbs to the Sun's glare at the start of April.

On this morning, however, Venus is an unmistakable beacon of magnitude –4.6 and positioned a bit less than 2½° from Regulus and about 5½° from the Moon. Notice, too, that the lunar crescent is adorned with a generous dose of *earthshine* — sunlight that lands on the Moon's surface after it has reflected off our planet. This "twice-reflected sunlight" (as *S&T* Contributing Editor Chuck Wood dubbed it) makes it possible for us to see the "unlit" portion of the lunar disk.

SATURDAY, OCTOBER 14

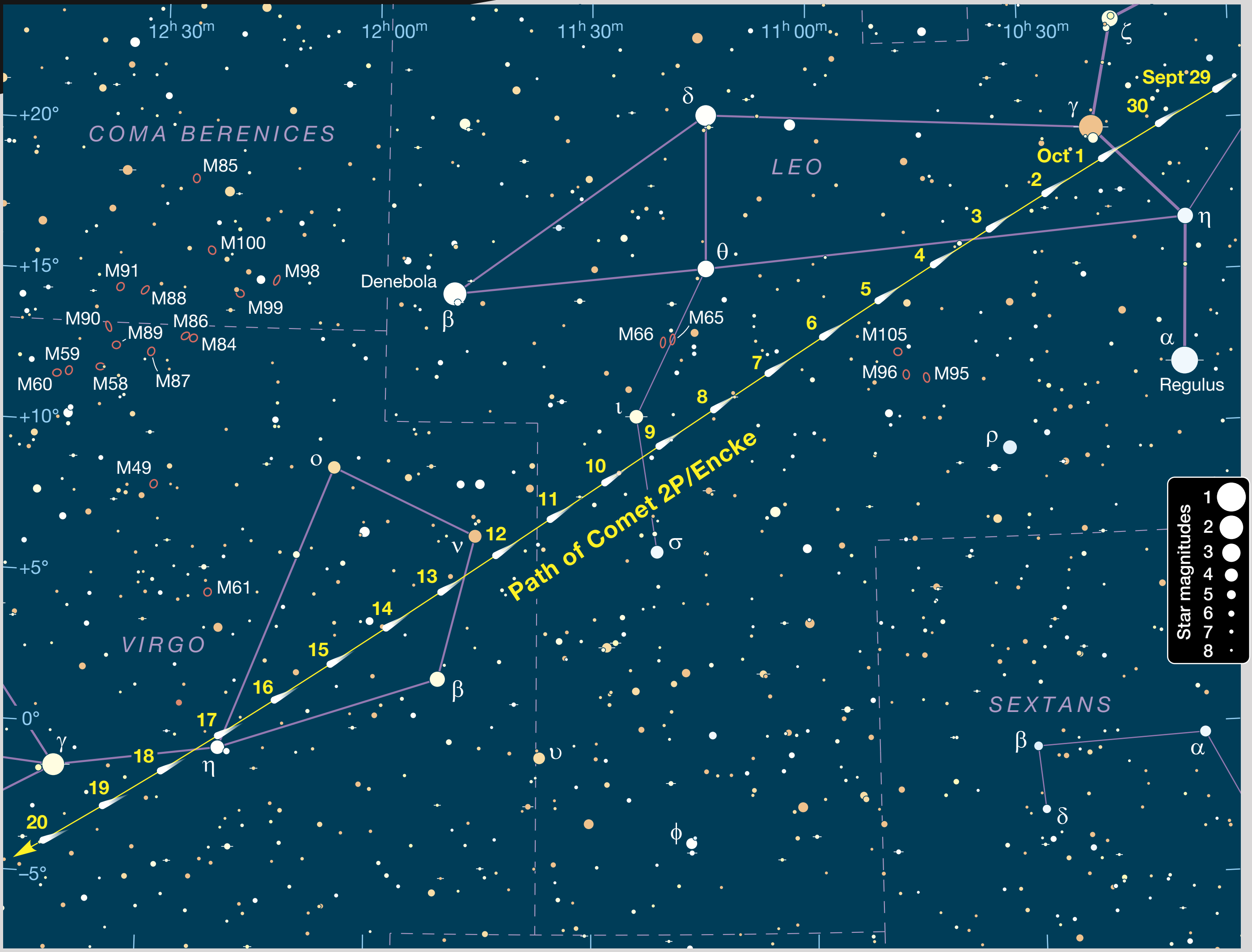
Today you have the rare chance of seeing the new **Moon** — but only if you take precautions. Such a sight is only possible during a solar eclipse. Most readers will get to enjoy at least some of today's annular event, during which the Moon passes in front of the **Sun**. So, get out your eclipse glasses and enjoy the show. (You can find complete details starting on page 34.)

But wait . . . there's more! Two weeks later (on the 28th), the Moon is full and clips Earth's shadow, producing a partial lunar eclipse. Turn to page 50 for more on that event.

SATURDAY, OCTOBER 28

The month winds down with a nice bit of symmetry as the **Moon** encounters **Jupiter** for a second time. This evening's event is an echo of the one that occurred on the 1st. This time as the Moon rises it's nearly full — only hours after being exactly so. Full Moon officially occurred late in the afternoon at 4:24 p.m. EDT. This evening, the Moon rises in deepening twilight about 20 minutes before Jupiter, and with 3½° separating them in the sky. Since the Moon lies to Jupiter's west, the gap between them will continue to slowly narrow throughout the night. The two are at their very closest at 2:13 a.m. EDT on the morning of the 29th, when less than 2½° separates them.

■ Consulting Editor **GARY SERONIK** keeps a close eye on the comings and goings of the Moon and planets from his home in southern British Columbia's Okanagan Valley.



Comet Encke's Brief Return

▲ The comet's positions are plotted for 0^h UT.

A frequent visitor makes a swing through the dawn sky.

Every 3.3 years Comet 2P/Encke makes its rounds of the inner solar system. It does so again this autumn with a modest appearance in the eastern sky before dawn. Although closest approach to Earth occurs on September 24th at a distance of 0.9 a.u., the comet is expected to peak at around magnitude 7 when it reaches perihelion on October 22nd. Unfortunately, it's lost in the Sun's glare before that date and for the remainder of the year. The best viewing opportunity this time around spans the first few weeks of October.

Expect the comet to begin the month as a fuzzy, 10th-magnitude blob in central Leo. On the mornings of October 7th and 8th (local time) it passes about 3° from the Leo Triplet galaxy group (M65, M66, and NGC 3628), creating a tempting, wide-field photo op. Encke slips into Virgo on the morning of the 11th, and a very thin waning crescent Moon (5%-illuminated) sits about 1½° northwest of the comet on the 12th.

Despite its sunward plunge, Encke's steadily rising brightness should help extend its visibility even as its altitude decreases and twilight encroaches. Around mid-month, it should glow at about magnitude 7.5 and feature a strongly condensed coma and a narrow, west-pointing tail.

In 1786, French astronomers Pierre Méchain and Charles Messier were the first to observe the comet, followed by Caroline Herschel in 1795, and finally Jean-Louis Pons in 1818. But it was German astronomer Johann Franz Encke who linked these observations to the appearance of a single object, much as Edmund Halley had done the previous century with the object that would eventually bear his name. Encke published his conclusions in 1819 and correctly predicted the comet's 1822 return, making it only the second to have its orbit calculated.

Dark Skies for the Orionids

HALLEY'S COMET MAY be one of the darkest objects in the solar system, but every October the Orionid meteor shower reveals the icy object's sparkly side. Coal-black dust jettisoned from Halley's nucleus forms a broad stream of debris that lies directly in Earth's orbital path. Beginning in early October, our planet plows through this trail of Halley dust, like a car driving through a rainstorm. But instead of raindrops splatting on the windshield, comet flakes pummel Earth's upper atmosphere, where they heat up and vaporize to produce fast, bright meteors.

The Orionids peak in the small hours of October 22nd, with 15 to 20 meteors visible per hour from a dark-sky location. They appear to radiate from a point in Orion's upraised club, a little more than 10° northeast of Betelgeuse. Although the radiant rises above the eastern horizon well before midnight, the best views of the display will come between 2 a.m. and dawn when Orion commands the sky — the higher the radiant, the less the horizon gets in the way. The last-quarter Moon sets shortly before midnight and won't disturb our view of Halley's luminiferous splinters.

Traveling at 238,000 kilometers per hour (148,000 miles per hour), Orionids often leave persistent trains in their wakes. A particle's swift flight ionizes both its surface and the nearby air, causing both to luminesce. The duration, brightness, and intensity of trains vary according to the size of meteoroid involved. A large one can leave a substantial amount of fine dust in its wake, which lingers long after the initial streak has faded. Upper atmospheric winds blowing at altitudes of around 100 km often distort these bright afterglows into twisty corkscrews and other shapes.

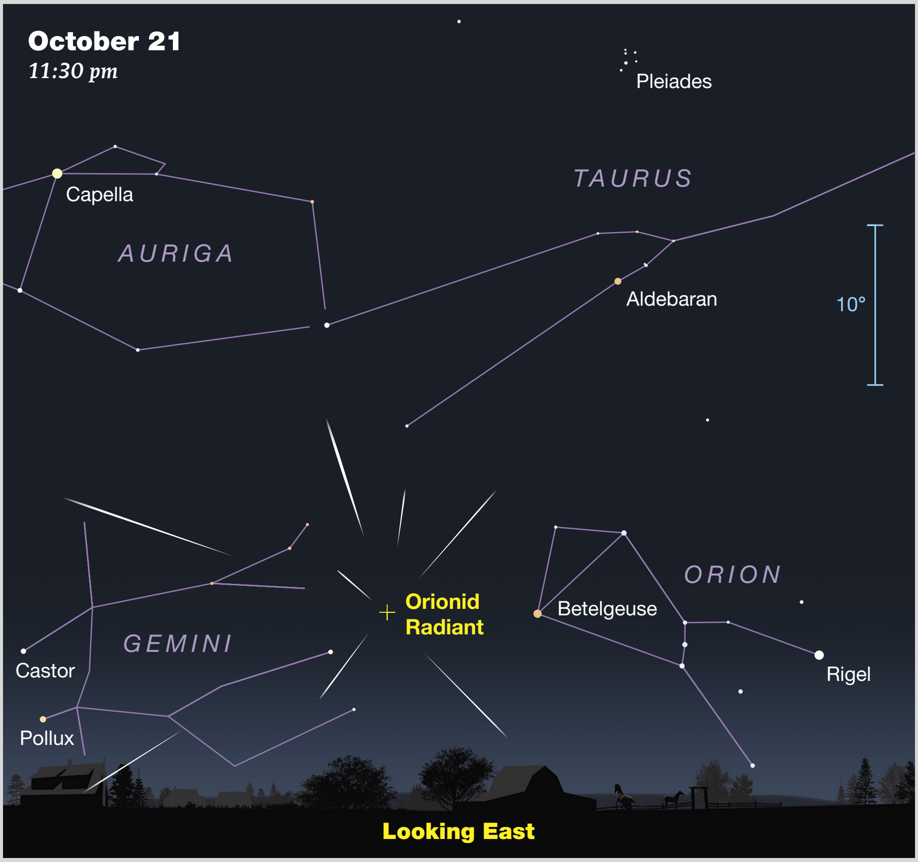
Earth enters the expansive swath of Halley's debris in early October and doesn't depart until the first week of November. That means the Orionid peak is a broad one, so if clouds threaten on the 22nd, the morning before or after that date might be nearly as good. Although considered a medium-strength shower, the Orionids are exciting to watch because they're speedy and stream from a photogenic location. Use a wide-angle lens to record the display and be sure to include Orion in the picture. I use an intervalometer to continuously snap 30-second exposures with my camera set to ISO 1600 and the lens open to its maximum aperture.

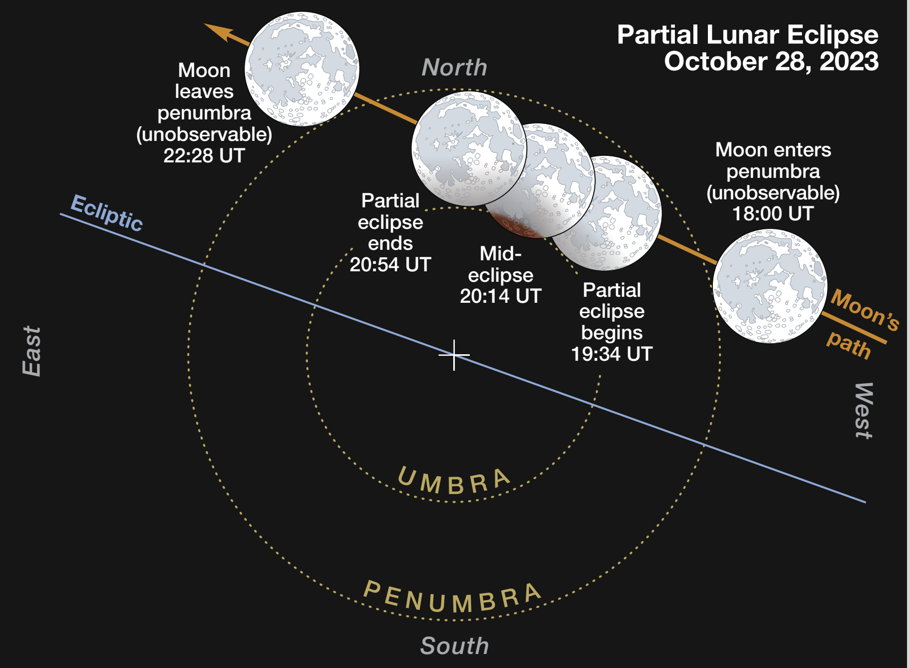
To simply view the show, relax in a reclining lawn chair tilted back so your gaze is centered roughly between the zenith and the radiant. However, if light pollution is a problem, turn your chair to face the darkest part of your sky. No matter where you look the probability of seeing an Orionid is about the same since the meteors fan out across the entire sky from the radiant. You'll likely also notice several "wrong-way" sporadic meteors. Telling the difference between these and shower members is easy — Orionid streaks point back to Orion.

If you'd like to contribute observations to help researchers better understand the evolution of the shower, check out the American Meteor Society's Visual Observing page at **https://is.gd/ams_program**.

▶ This composite photo shows Orionid meteors captured from October 19 to 23, 2020. Various emission nebulae are also visible, along with a foreground that includes five extinct volcanoes and skyglow from the city Prešov in the Slovak Republic.

PETR HORÁLEK





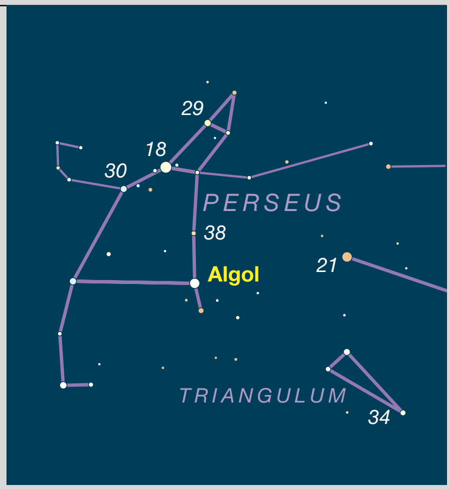
A Very Partial Lunar Eclipse

THE FULL HUNTER'S MOON traverses the outer fringe of Earth's inner shadow on the night of October 28–29. Although this partial lunar eclipse is primarily visible across Europe, Africa, Asia, and Australia, observers in easternmost Canada will also get a taste of the event. At mid-eclipse (20:14 UT), only 5% of the lunar disk dips into Earth's umbra. From London, England, the Moon stands well up in the eastern sky and just 5.9° west-southwest of brilliant Jupiter at mid-eclipse.

Minima of Algol

Sept.	UT	Oct.	UT
2	21:09	1	13:15
5	17:58	4	10:04
8	14:46	7	6:53
11	11:35	10	3:42
14	8:23	13	0:30
17	5:12	15	21:19
20	2:01	18	18:08
22	22:49	21	14:57
25	19:38	24	11:46
28	16:27	27	8:34
		30	5:23

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.



▲ Perseus reaches the zenith during pre-dawn hours in October. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

AS OCTOBER BEGINS, Jupiter is a conspicuous evening-sky sight when it rises in the east-northeast at around 8:10 p.m. local daylight time. The planet transits the meridian (when it's due south and at its highest) shortly after 3 a.m. By the end of the month, it both rises and transits two hours earlier. In that same span Jupiter remains nearly the same brightness (increasing imperceptibly from magnitude –2.8 to –2.9) as its disk swells modestly from 47.7″ to 49.5″. This is prime observing season for Jupiter enthusiasts as the planet nears its November 3rd opposition date.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Of special note is a favorable double shadow transit involving Ganymede and Io, on October 20th from 1:58 a.m. to 3:41 a.m. EDT (5:58 to 7:41 UT).

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

September 1: 7:28, 17:24; **2**: 3:19, 13:15, 23:11; **3**: 9:06, 19:02; **4**: 4:58, 14:53; **5**: 0:49, 10:44, 20:40; **6**: 6:36, 16:31; **7**: 2:27, 12:23, 22:18; **8**: 8:14, 18:09; **9**: 4:05, 14:01, 23:56; **10**: 9:52, 19:48; **11**: 5:43, 15:39; **12**: 1:34, 11:30, 21:26; **13**: 7:21, 17:17; **14**: 3:13, 13:08, 23:04; **15**: 8:59, 18:55; **16**: 4:51, 14:46; **17**: 0:42, 10:37, 20:33; **18**: 6:29, 16:24; **19**: 2:20, 12:15, 22:11; **20**: 8:07, 18:02; **21**: 3:58, 13:53, 23:49; **22**: 9:45, 19:40; **23**: 5:36, 15:31; **24**: 1:27, 11:23, 21:18; **25**: 7:14, 17:09; **26**: 3:05, 13:01, 22:56; **27**: 8:52, 18:47; **28**: 4:43, 14:39; **29**: 0:34, 10:30, 20:25; **30**: 6:21, 16:17

October 1: 2:15, 12:11, 22:07: **2**: 8:02, 17:58: **3**: 3:53, 13:49, 23:44: **4**: 9:40, 19:36: **5**: 5:31, 15:27: **6**: 1:22,

ECLIPSE DIAGRAM: LEAH TISCIONE / *S&T*, SOURCE: USNO

11:18, 21:14: **7**: 7:09, 17:05: **8**: 3:00, 12:56, 22:51: **9**: 8:47, 18:43: **10**: 4:38, 14:34: **11**: 0:29, 10:25, 20:21: **12**: 6:16, 16:12: **13**: 2:07, 12:03, 21:58: **14**: 7:54, 17:50: **15**: 3:45, 13:41, 23:36: **16**: 9:32, 19:27: **17**: 5:23, 15:19: **18**: 1:14, 11:10, 21:05: **19**: 7:01, 16:57: **20**: 2:52, 12:48, 22:43: **21**: 8:39, 18:34: **22**: 4:30, 14:26: **23**: 0:21, 10:17, 20:12: **24**: 6:08, 16:03: **25**: 1:59, 11:55, 21:50: **26**: 7:46, 17:41: **27**: 3:37, 13:33, 23:28: **28**: 9:24, 19:19: **29**: 5:15, 15:10: **30**: 1:06, 11:02, 20:57: **31**: 6:53, 16:48

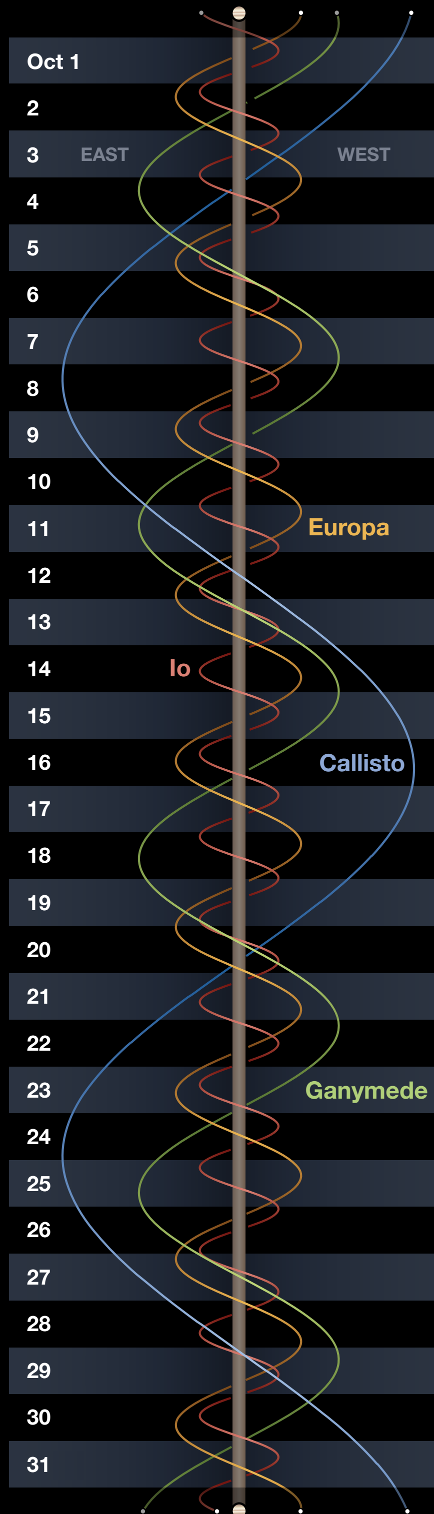
These times assume that the spot will be centered at System II longitude 46° on October 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 46° and $1\frac{2}{3}$ minutes later for each degree more than 46°.

Phenomena of Jupiter's Moons, October 2023

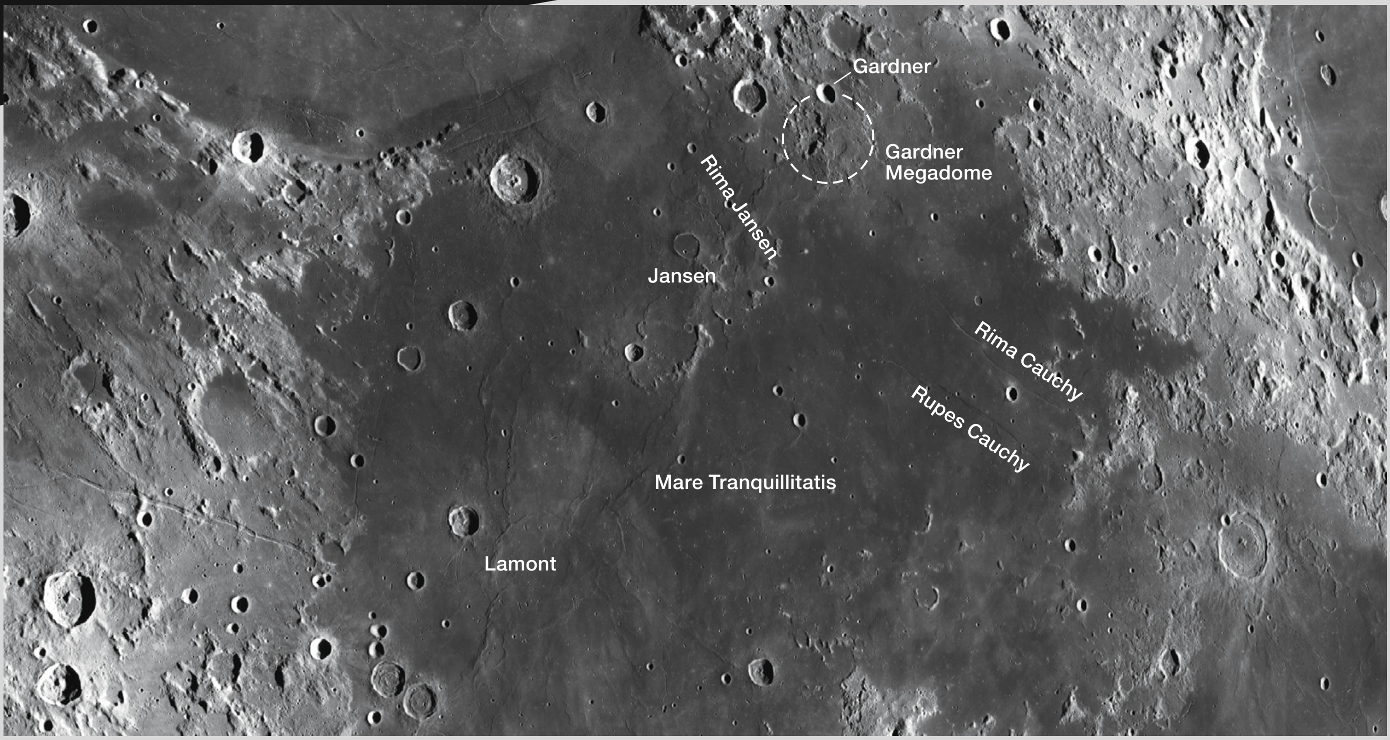
Oct. 1	6:26	II.Ec.D
	10:20	II.Oc.R
	15:44	I.Ec.D
	18:41	I.Oc.R
Oct. 2	7:45	III.Ec.D
	9:33	III.Ec.R
	11:25	III.Oc.D
	12:15	III.Oc.R
	12:52	I.Sh.I
	13:40	I.Tr.I
	15:02	I.Sh.E
	15:48	I.Tr.E
Oct. 3	1:35	II.Sh.I
	3:11	II.Tr.I
	3:54	II.Sh.E
	5:23	II.Tr.E
	10:13	I.Ec.D
	13:08	I.Oc.R
Oct. 4	7:21	I.Sh.I
	8:07	I.Tr.I
	9:31	I.Sh.E
	10:14	I.Tr.E
	19:44	II.Ec.D
	23:29	II.Oc.R
Oct. 5	4:42	I.Ec.D
	7:34	I.Oc.R
	21:55	III.Sh.I
	23:41	III.Sh.E
Oct. 6	1:19	III.Tr.I
	1:50	I.Sh.I
	2:03	III.Tr.E
	2:33	I.Tr.I
	3:59	I.Sh.E
	4:41	I.Tr.E
	14:53	II.Sh.I
	16:20	II.Tr.I
	17:12	II.Sh.E
	18:31	II.Tr.E
	23:10	I.Ec.D
Oct. 7	2:00	I.Oc.R
	20:18	I.Sh.I
	20:59	I.Tr.I
	22:28	I.Sh.E
	23:07	I.Tr.E
Oct. 8	9:02	II.Ec.D
	12:38	II.Oc.R
	17:39	I.Ec.D
	20:26	I.Oc.R
Oct. 9	11:46	III.Ec.D
	13:33	III.Ec.R
	14:47	III.Oc.D
	14:47	I.Sh.I
	15:25	I.Tr.I
	15:37	III.Oc.R
	16:57	I.Sh.E
	17:33	I.Tr.E
Oct. 10	4:10	II.Sh.I
	5:28	II.Tr.I
	6:30	II.Sh.E
	7:39	II.Tr.E
	12:07	I.Ec.D
	14:52	I.Oc.R
Oct. 11	9:15	I.Sh.I
	9:51	I.Tr.I
	11:25	I.Sh.E
	11:59	I.Tr.E
	22:21	II.Ec.D
Oct. 12	1:46	II.Oc.R
	6:36	I.Ec.D
	9:18	I.Oc.R
Oct. 13	1:56	III.Sh.I
	3:41	III.Sh.E
	3:44	I.Sh.I
	4:17	I.Tr.I
	4:38	III.Tr.I
	5:24	III.Tr.E
	5:54	I.Sh.E
	6:25	I.Tr.E
	17:28	II.Sh.I
	18:35	II.Tr.I
	19:48	II.Sh.E
	20:47	II.Tr.E
Oct. 14	1:04	I.Ec.D
	3:44	I.Oc.R
	22:12	I.Sh.I
	22:43	I.Tr.I
Oct. 15	0:23	I.Sh.E
	0:52	I.Tr.E
	11:39	II.Ec.D
	14:55	II.Oc.R
	19:33	I.Ec.D
	22:10	I.Oc.R
Oct. 16	15:47	III.Ec.D
	16:41	I.Sh.I
	17:10	I.Tr.I
	17:34	III.Ec.R
	18:05	III.Oc.D
	18:51	I.Sh.E
	18:57	III.Oc.R
	19:18	I.Tr.E
Oct. 17	6:46	II.Sh.I
	7:42	II.Tr.I
	9:05	II.Sh.E
	9:54	II.Tr.E
	14:02	I.Ec.D
	16:36	I.Oc.R
Oct. 18	11:10	I.Sh.I
	11:35	I.Tr.I
	13:20	I.Sh.E
	13:44	I.Tr.E
Oct. 19	0:58	II.Ec.D
	4:02	II.Oc.R
	8:30	I.Ec.D
	11:02	I.Oc.R
Oct. 20	5:38	I.Sh.I
	5:57	III.Sh.I
	6:01	I.Tr.I
	7:41	III.Sh.E
	7:49	I.Sh.E
	7:53	III.Tr.I
	8:10	I.Tr.E
	8:42	III.Tr.E
	20:04	II.Sh.I
	20:49	II.Tr.I
	22:23	II.Sh.E
	23:01	II.Tr.E
Oct. 21	2:59	I.Ec.D
	5:28	I.Oc.R
Oct. 22	0:07	I.Sh.I
	0:27	I.Tr.I
	2:17	I.Sh.E
	2:36	I.Tr.E
	14:17	II.Ec.D
	17:10	II.Oc.R
	21:27	I.Ec.D
	23:54	I.Oc.R
Oct. 23	18:36	I.Sh.I
	18:53	I.Tr.I
	19:49	III.Ec.D
	20:46	I.Sh.E
	21:02	I.Tr.E
	22:16	III.Oc.R
Oct. 24	9:22	II.Sh.I
	9:56	II.Tr.I
	11:41	II.Sh.E
	12:08	II.Tr.E
	15:56	I.Ec.D
	18:20	I.Oc.R
Oct. 25	13:04	I.Sh.I
	13:19	I.Tr.I
	15:15	I.Sh.E
	15:28	I.Tr.E
Oct. 26	3:35	II.Ec.D
	6:17	II.Oc.R
	10:25	I.Ec.D
	12:46	I.Oc.R
Oct. 27	7:33	I.Sh.I
	7:45	I.Tr.I
	9:43	I.Sh.E
	9:53	I.Tr.E
	9:58	III.Sh.I
	11:06	III.Tr.I
	11:42	III.Sh.E
	12:00	III.Tr.E
	22:39	II.Sh.I
	23:03	II.Tr.I
Oct. 28	0:59	II.Sh.E
	1:15	II.Tr.E
	4:53	I.Ec.D
	7:12	I.Oc.R
Oct. 29	2:02	I.Sh.I
	2:11	I.Tr.I
	4:12	I.Sh.E
	4:19	I.Tr.E
	16:54	II.Ec.D
	19:25	II.Oc.R
	23:22	I.Ec.D
Oct. 30	1:37	I.Oc.R
	20:31	I.Sh.I
	20:37	I.Tr.I
	22:41	I.Sh.E
	22:45	I.Tr.E
	23:50	III.Ec.D
Oct. 31	1:36	III.Ec.R
	11:57	II.Sh.I
	12:09	II.Tr.I
	14:17	II.Sh.E
	14:22	II.Tr.E
	17:51	I.Ec.D
	20:03	I.Oc.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.



No Tranquil Solution

Mare Tranquillitatis doesn't appear to fill an impact basin. Why not?

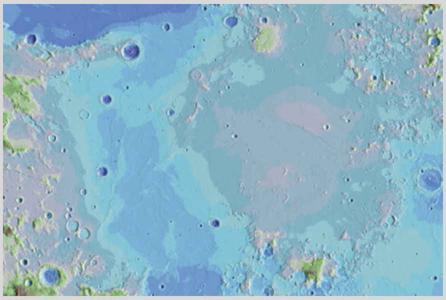
The major lunar maria tend to fill large impact basins. Imbrium, Serenitatis, Humorum, and Crisium all fit this pattern. So why doesn't **Mare Tranquillitatis**? It's a vast lava plain seemingly without an underlying basin. Or is there one?

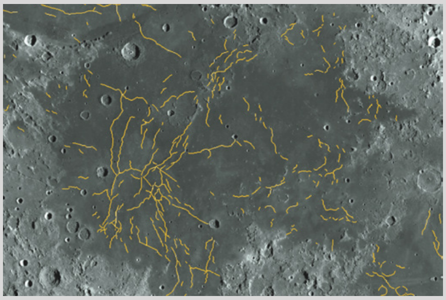
Major impact basins on the Moon span from about 300 to some 2,000 kilometers (185 to 1,250 miles) wide. These are mega-craters that excavated broad, deep cavities and deeply fractured the underlying crust, creating conduits that allowed magma from the lunar mantle to erupt onto the surface. Today they appear as circular lava plains some 3 to 5 km deep, with concentric inner rings and partially surrounded by arcuate mountain ranges.

Until recently, the traditional morphological characteristics of basins were identified visually. Now, with instruments aboard NASA's Lunar Reconnaissance Orbiter (LRO) and data provided by the Gravity Recovery and Interior Laboratory (GRAIL), we can image below the surface to understand the underlying structure of basins. These data reveal that the basins have thin crusts (due to the excavation during formation) and circular gravity anomalies characterized by excess mass in their centers surrounded by collars with lower mass. This central mass concentration is caused by a rebound of dense mantle rocks beneath the thinned crust with some contribution from the kilometers-thick piles of lava on top. The surrounding collars are thought to be due to the pile-up of fragmented ejecta.

The co-registered collection of data at the QuickMap Moon website (**https://is.gd/quickmap**) permits an easy means to investigate if Tranquillitatis has a hidden underlying basin. Looking first at the LRO Wide-Angle Camera image of Tranquillitatis, it's obvious that the mare isn't circular, having a north-south dimension of about 525 km and extending roughly

▼▶ These five images show different aspects of Mare Tranquillitatis ordered left to right. The first picture displays laser altimeter elevation measurements, with blue representing the lowest area. The next highlights mare ridges. On the facing page, the left image displays the crustal thickness, with thickest areas as orange. In the middle is a Bouguer gravity map with positive values assigned red and negative values blue. The final map shows the gravity gradients that cross the maria.





ALL IMAGES COURTESY OF NASA / GSFC / ARIZONA STATE UNIVERSITY

700 km east to west. There isn't a hint of a mountainous basin rim such as **Montes Apenninus** and **Montes Carpatus** circling part of **Mare Imbrium**. Additionally, QuickMap's overlay of wrinkle ridges at Tranquillitatis reveals ridges, but they don't define inner rings or any other basin structure. The greatest concentration of ridges is in the west half of the mare and traces concentric and radial structures of **Lamont**, which is thought to be either a lava-covered, two-ring impact basin or an unusual buried volcanic structure. Another concentration of ridges marks a volcanic complex east of **Jansen** crater.

A final morphological aspect of Mare Tranquillitatis is its uneven depth. Instead of a broad, symmetrical depression, the western half (centered on Lamont) is a 450-km-long, 275-km-wide depression that sits 2.2 km below the average lunar elevation. The east side of the mare is a shallow, 400-km-wide, roughly circular area only 0.5 km below the average elevation. The crustal thickness reflects these surface elevation differences, with Lamont having a crust only 10 to 15 km thick, whereas the crust under the eastern half of the mare ranges from 25 to 40 km thick.

Precise gravity measurements provided by GRAIL also show that, unlike many impact basins having a positive gravity anomaly across their center, Tranquillitatis has only an elongated mass concentration following the topographic trough and thin crust of its western half. Two smaller, circular mass concentrations occur near Jansen and the **Gardner Megadome**, a volcanic mountain and caldera that I informally named in 2004.

A final piece of geophysical data is provided by GRAIL-derived gravity gradient maps. A *gravity gradient* occurs where two adjacent regions have different masses and densities. Across the Moon, concentrations of positive gravity gradients (shown as deep blue on QuickMap) are found under many basins. There are also narrow, linear blue zones (that I call worms) under many mare ridges, which sometimes link volcanic structures. The worms are interpreted as places where the deep lunar crust was pulled apart and filled with high-density magma. The blue worms represent geologic dikes that probably supplied the magma that erupted onto the surface as lava flows in some areas or as other volcanic features elsewhere.

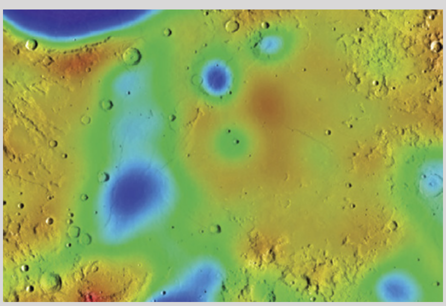
The morphological and geophysical data for Tranquillitatis don't support the existence of an impact basin under its mare surface. The lack of a mountainous rim, and the great differences of the mare topography, its crustal thickness, mare ridge distribution, and gravity anomalies and gradients are all inconsistent with large impact basins. Furthermore, the topographically low surface trough at the same location as a major deep gravity worm indicates that the trough isn't related to surface effects such as the excavation of a giant basin.

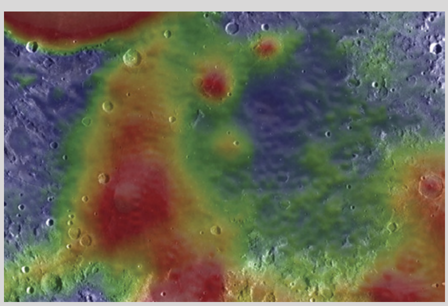
Instead, several characteristics of Tranquillitatis are associated with volcanism. First, the fact that Lamont is located over a wide gravity worm strongly suggests the feature is of volcanic origin, rather than a buried impact basin. Second, the 100-km-wide, circular crustal thickness and positive gravity anomaly to the east of Jansen is consistent with a buried impact crater. However, this area is also located on a strong gravity worm, indicating a connection with deep magma. The region also has a high concentration of linear ridges, rather than the circular ridges that would be typical for a buried impact structure. Additionally, the Jansen area is a source of the sinuous **Rima Jansen** and a 6-km-long collapse feature. While Jansen crater may be of impact origin, a third nearby volcanic structure is the aforementioned 80-km-wide, 1.2-km-high Gardner megadome.

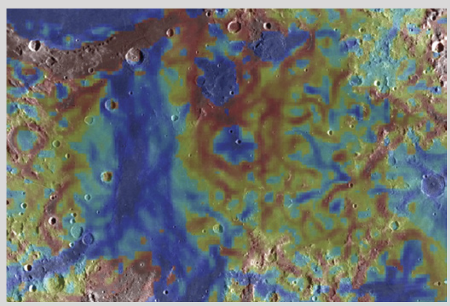
The most unexpected feature of Mare Tranquillitatis is the 400-km-wide circular rise that covers most of the mare's eastern portion and includes a 250-km-long, 600-m-high area that reaches its highest elevation between **Rupes Cauchy** and **Rima Cauchy**. The fault forms a sharp, 300-m-high jump in elevation, and at the rille the summit rise begins a smooth, downward slope towards the northeast shore of the mare.

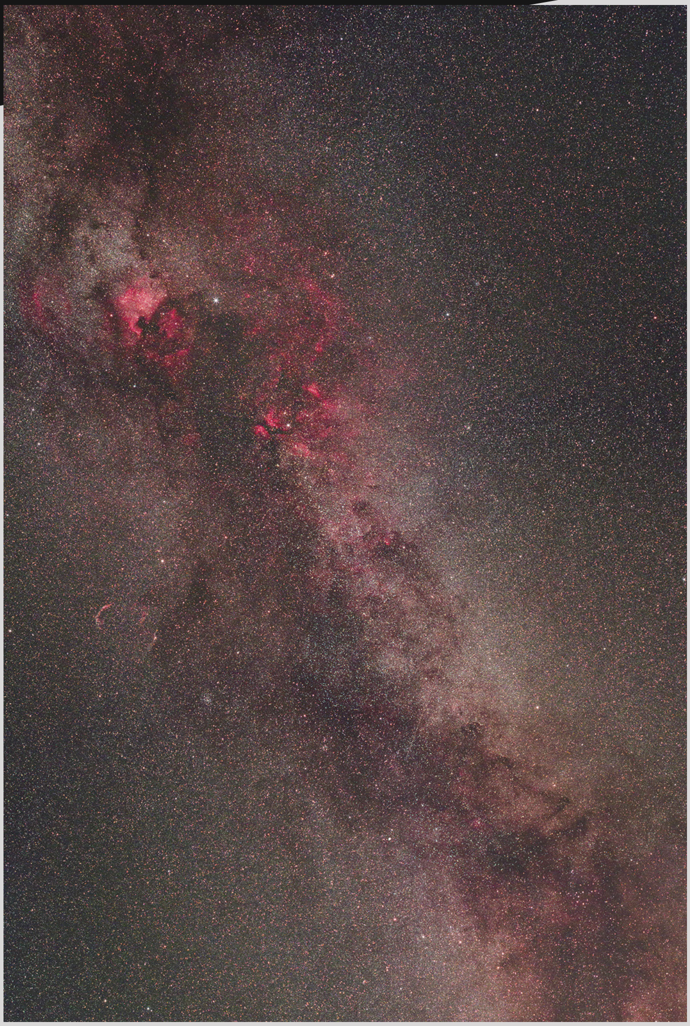
Recently, Le Qiao of Shandong University in China and colleagues cataloged 283 small volcanic domes, almost all in the east portion of Tranquillitatis. They posit that the broad volcanic rise was built up from innumerable, small-volume eruptions originating with earlier volcanic domes. They proposed that such domes were the main sources of Mare Tranquillitatis lavas. Like nearly all previous researchers, Qiao's team accepts that an ancient, now degraded basin must have created fractures to magma source regions and formed a depression to collect the lavas. But because the evidence for a basin is quite weak, perhaps the question should be asked if maria ever formed without the benefit of a basin predecessor.

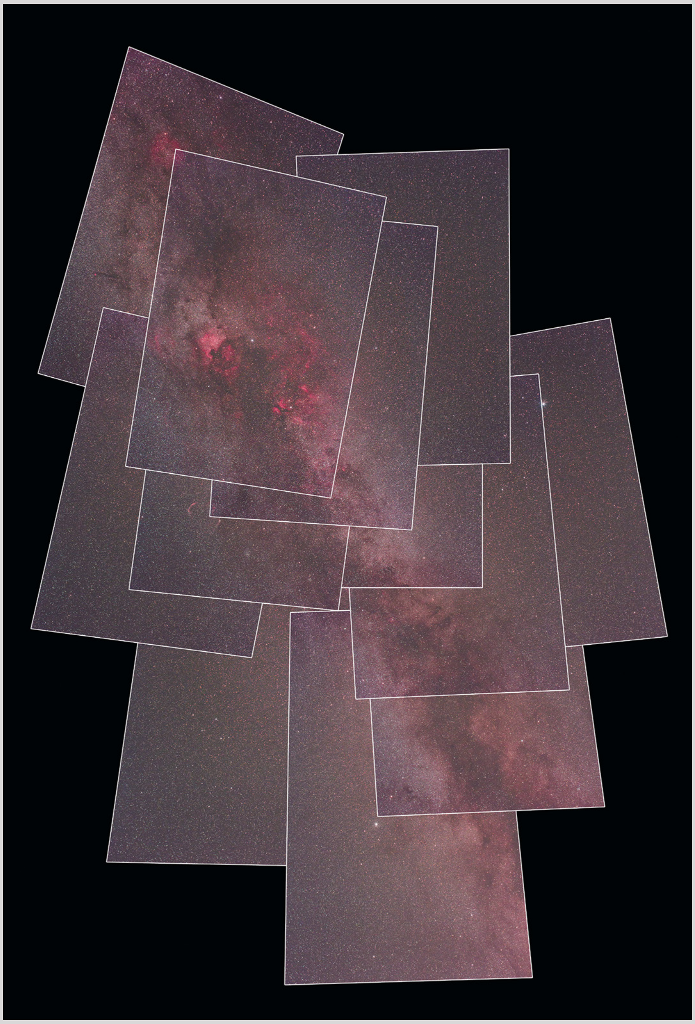
■ Contributing Editor **CHUCK WOOD** has climbed small volcanic domes in Idaho and Iceland but none yet on the Moon.











Detailed Wide-Angle Astrophotos

Overlapping frames allow you to capture generous swaths of sky in high resolution.

Stunning, wide-field images of the night sky are possible with nothing more than a modern digital camera, a fast wide-angle lens, and a sturdy tripod. Add a dark-sky location with a compelling landscape, and you have all the ingredients necessary for an award-worthy photograph. Still, there's room for improvement.

As impressive as typical wide-angle shots can be, it's always a bit disappointing when you zoom in to examine the details. Deep-sky objects are rendered as nothing more than indistinct blobs of color just a few pixels wide. Even with the tremendous resolution of modern camera sensors, wide-angle lenses simply can't deliver enough detail to display small objects clearly.

Luckily there's a trick you can employ to create extremely high-resolution, wide-angle images. The "trick" is to use a longer focal-length lens and stitch multiple, overlapping frames into a single, highly detailed, wide-field image. Although such photos take more time and planning to create, the resulting resolution lets you explore the complexity and breathtaking beauty of the night sky down to the pixel level.

Connecting the Shots

I have to admit my first attempt at using this technique was a total failure. Back in the film days, I tried to create a wide-field panoramic image of the Milky Way by pasting together

▲ **WIDE AND SHARP** *Left:* The author cropped this expansive photo of the Cygnus Milky Way from the 12-tile mosaic shown at right. The technique described in this article allows you to create the kinds of photos normally produced with a wide-angle lens, but with a level of detail only a longer-focal-length optic is capable of. *Right:* A total of 12 individual images (each outlined in white) were combined to create this mosaic. Each individual, 2-minute exposure was captured with a Canon 50-mm f/1.4 lens working at f/2.8 and an astro-modified Canon 60D camera working at ISO 1600. The resulting image file is about 200 megapixels in size and shows incredible detail.

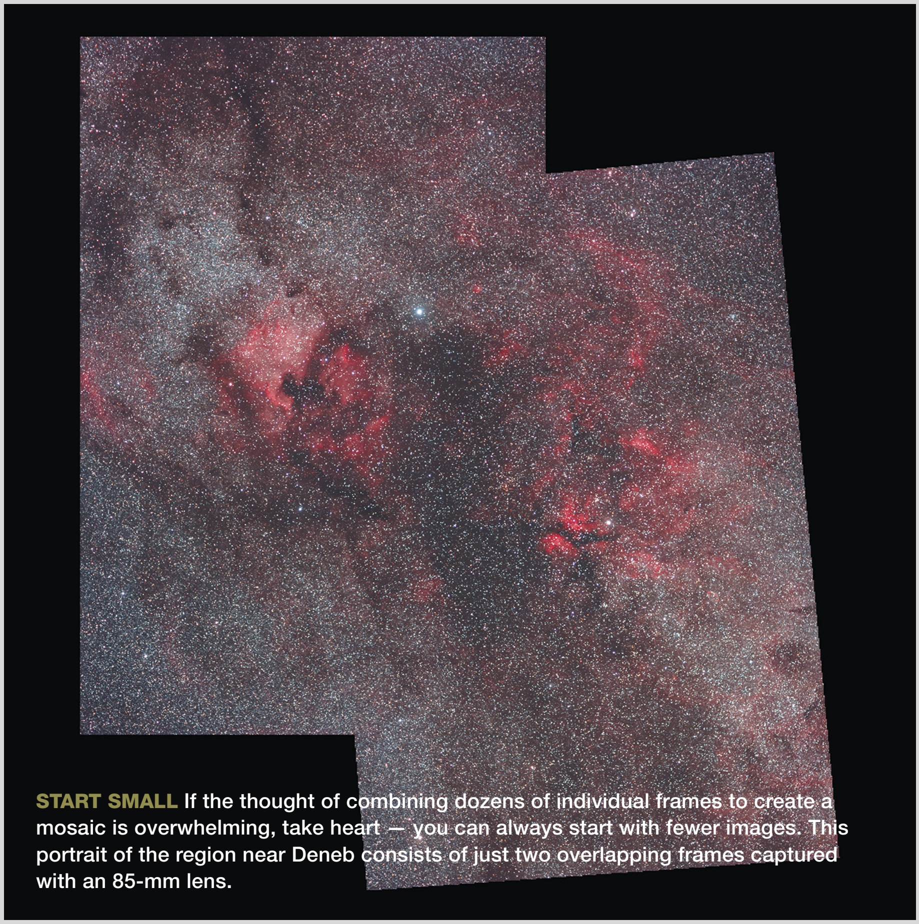
several 4×6 prints made with a 35-mm camera and a 50-mm lens. Despite including a fair bit of overlap between each photo, it was impossible to make the flat paper prints match to the spherical shape of the night sky. This, along with heavy vignetting at the edge of each image, made for a rather sad-looking photo project.

Fast-forward a few decades and it's now possible to use the built-in panorama features in image-editing software to automatically apply the proper corrections and merge the individual frames into a single, seamless, wide-angle image. I find *Adobe Lightroom* the easiest to use. Plus, it has the ability to save your merged image as a DNG file, which allows extensive post-processing. Other options include *Adobe Photoshop*, *Affinity Photo*, and *PTGUI*. Each of these programs requires a significant amount of overlap between the individual image tiles to perform their digital magic, so careful planning is important to ensure the best results.

Each time you take a shot, pick a star that's about one-third of the way in from the edge of the frame and use it as a reference point to line up the edge of the next image in the sequence. You can follow either a simple linear arrangement or execute a cross-like pattern in which the central image is surrounded by additional frames on all four sides. Even with a 50-mm lens on a full-frame camera, you can quickly cover impressively wide regions of the night sky. However, as your lens focal length increases, the process requires more frames in order to cover the same field of view and therefore takes substantially longer to shoot.

You might be tempted to use the absolute minimum number of shots possible to photograph a given area, but in my experience it's better to strive for more coverage rather than less. A generous amount of overlap ensures that you won't discover any unsightly gaps when you stitch together your frames.

▲ **A QUESTION OF RESOLUTION** This pair of cropped images of the region near Deneb, in Cygnus, shows the dramatic difference in detail captured by a 50-mm lens (left) and a 15-mm fisheye (right). Note how sharp the stars are and how well defined the nebulosity is in the 50-mm shot.

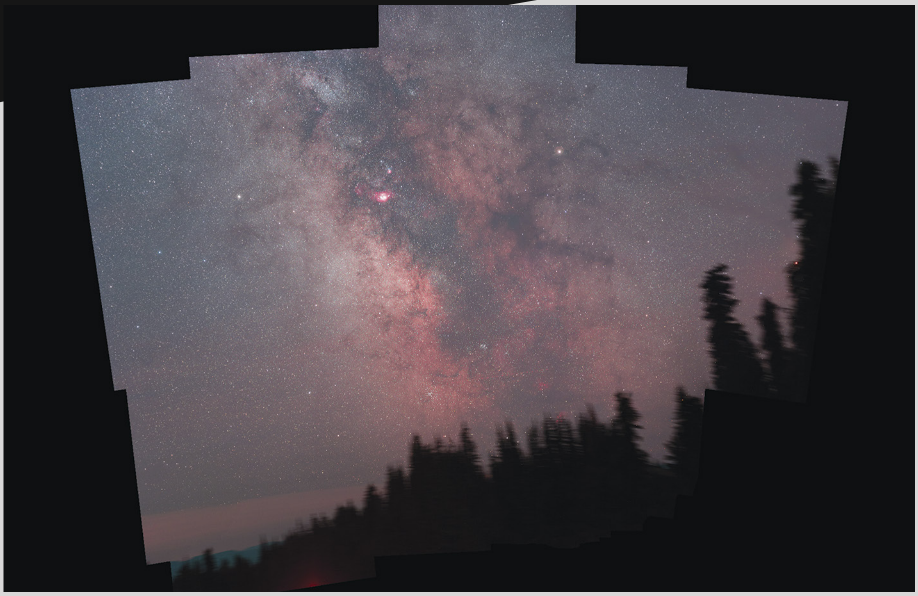


START SMALL If the thought of combining dozens of individual frames to create a mosaic is overwhelming, take heart — you can always start with fewer images. This portrait of the region near Deneb consists of just two overlapping frames captured with an 85-mm lens.

Quick Tips

In the Northern Hemisphere, you should start your shooting sequence with the westernmost edge of your image set first. This allows you to maximize your sky coverage before Earth's rotation causes objects to sink into the muck near the horizon or, worse, set entirely. You don't want to be in a situation where you have to rush your shots. I'd also suggest shooting at least two exposures for each tile in your matrix just in case a passing satellite or aircraft spoils one of them. It's even possible to shoot the individual tiles over successive evenings so long as sky conditions remain consistent.

Desktop planetarium programs like *SkySafari* are helpful for pre-visualizing



▲ **SOUTHERN HORIZON** The author combined 13 individual frames photographed with an 85-mm lens to create this composite view of the Sagittarius Milky Way. Unlike with typical wide-angle shots, zooming in on this image reveals considerable detail in individual deep-sky objects. If desired, the mosaic can be cropped to create a final image suitable for printing or display.

the individual image tiles you'll need to create your final mosaic. Most of these programs can display a graphical overlay to indicate a specific field of view. Select a rectangular-shaped frame that matches your particular camera-and-lens combination. For example, my Canon EOS 60D with a 50-mm lens has a field of view measuring 25° × 17°.

Once you're ready to start shooting, put your camera in Manual mode and be sure to use the same ISO, aperture, and exposure setting for each frame. When shooting in RAW mode, the only post-processing required will be to set a consistent white balance across all the images. This will help everything blend neatly when you assemble your image.

Getting on Track

On your first attempts with this method, keep things simple by shooting with a fixed tripod. The main drawback to this approach is that your exposure time will be limited by your lens's focal length. Over time, the Earth's rotation causes the stars to drift across the sky and leave trails on your images. The effect is more pronounced with longer lenses. For example, a 16-mm lens (on a full-frame camera) allows an exposure of up to 30 seconds long without serious trailing. However, that same camera equipped with a 50-mm lens will be limited to just a 10-second exposure before the star trails start to show. (This topic was discussed in greater detail in the February 2023 issue, page 55.)

Fortunately, many lenses in the 50-mm focal-length range have extremely wide apertures (low f/stop numbers, such as f/1.8), which allows them to gather light more quickly than their slower, wide-angle cousins. This can partially compensate for the shorter exposure times you'll need to use. You can also boost your camera's ISO setting to keep exposure times suitably short.

For lenses with even longer focal lengths, you'll need a tracking mount to achieve untrailed stars. Lightweight units such as the iOptron SkyTracker Pro or Sky-Watcher Star Adventurer are simple, portable options. For larger telephoto lenses, a more substantial equatorial mount will be required to carry the extra weight. Although I've used this technique exclusively with camera lenses, there's no reason you can't extend it to include images captured with a telescope. For example, if you have trouble fitting the full extent of the Andromeda Galaxy (or even the Moon) in your photo, you can shoot multiple, overlapping frames to create a synthetic wide-field view while retaining the exquisite detail that a long-focus instrument provides. Indeed, some of my best Moon shots have been captured this way.

Panning for Gold

Once you've imported your images into your computer, it's a simple matter to blend the images together with image-editing software. In *Adobe Lightroom* you simply select ***Photo > Photo Merge > Panorama Merge***. This will launch the Panorama Merge Preview dialog box. Three options are presented for the type of projection used to create the final panorama: Spherical, Cylindrical, and Perspective. Experiment to see which one provides the most aesthetically pleasing results for your particular set of shots. Surprisingly, *Lightroom* and *Photoshop* seem to have slightly different algorithms for blending panoramas, so if one program fails to work well, try using the other.

For most of the images in this article, I've left the ragged, saw-tooth outline of the individual image tiles visible. If you prefer, you can crop your resulting mosaics so they have a more traditional rectangular shape, which makes them easier to display on your monitor. And by carefully planning the initial arrangement of the tiles, you can create a final mosaic that supports both horizontal and vertical crops. This is handy if you plan to post the image on various social media platforms, each of which has its own preferred aspect ratio.

If the prospect of taking dozens of overlapped images seems a bit daunting, don't worry — you can start by using just a couple of frames. Once you're comfortable with the technique, you can attempt more elaborate and expansive shots. Eventually your confidence will grow, and soon you'll be making detailed, wide-angle photos that you'll be proud to post online and show to your friends and family.

■ **TONY PUERZER** is an avid amateur astrophotographer. He's happy that his photo mosaics no longer involve scissors, glue, and posterboard.

The Milky Way and the Seven Dwarfs

Spend October nights with a collection of remarkable galaxies.

In 1938, Harvard astronomer Harlow Shapley announced the discovery of a large but inconspicuous galaxy in Sculptor with an unusually low luminosity. It lacked a nucleus and star clusters, but long-exposure photographs resolved a few thousand faint stars. Shapley called it "A stellar system of a new type," as it didn't fit the classification scheme (elliptical, spiral, and lenticular) of Edwin Hubble's "tuning fork" diagram, updated just two years earlier. The strange galaxy was the first known *dwarf spheroidal* — now recognized as the most common variety in the Local Group!

Sculptor and Fornax

The **Sculptor Dwarf** is a low-mass satellite of the Milky Way at a distance of 270,000 light-years. It underwent a single episode of star formation that began 13 billion years ago and lasted for 2 billion years. Currently, the Sculptor Dwarf is dust- and gas-poor, with only metal-deficient stars spread throughout and somewhat younger, more iron-rich ones that are centrally concentrated. Research on the velocities of its stars shows the galaxy has a high mass-to-light ratio. The excess mass is the signature of a significant dark matter halo — a feature that distinguishes dwarf spheroidal galaxies from globular clusters.

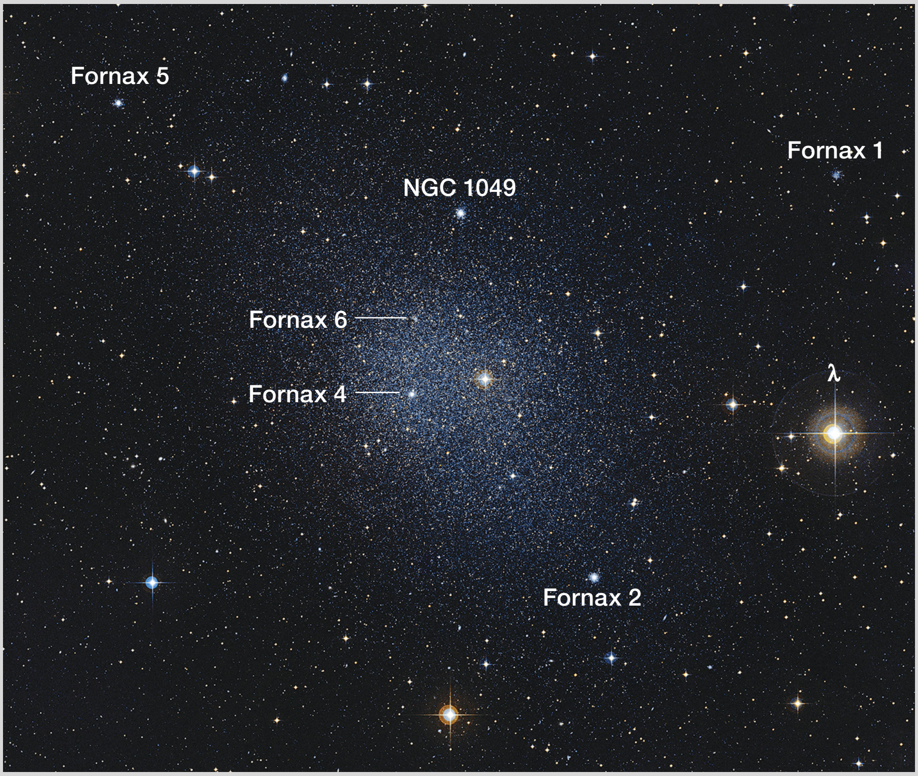
The Sculptor Dwarf and similar systems are key laboratories to test questions on the nature and distribution of dark matter. In 2017, a team led by Davide Massari (then at Kapteyn Astronomical Institute, the Netherlands) combined one-dimensional line-of-sight velocities with precise proper motion measurements to calculate three-dimensional stellar motions. Their data suggest Sculptor's dark matter halo is *cuspy* — meaning the density rises steeply at the center. This conclusion aligns with the standard cosmological model known as ΛCDM (lambda cold dark matter). But their results were tentative due to a small sample of 10 stars.

The Sculptor Dwarf has a visual magnitude of around 8.6, but don't be misled by this figure. Its light is spread over a 40′ × 31′ area, resulting in a very shallow contrast to the background sky. For observers at mid-northern latitudes, its low altitude — 4.3° south of 4.3-magnitude Alpha (α) Sculptoris — means that atmospheric dimming, haze, and local light domes may further reduce its visibility or render it completely invisible.

A few years ago, I observed the Sculptor Dwarf using my 18-inch telescope at 113× from a dark site at latitude 36.7° north, where the galaxy culminates 20° above the southern horizon. With some patience, I spied a large, ill-defined stain measuring 15′ to 18′ in diameter, with very little central concentration. Despite my difficulty, other amateurs

THE LOCAL GROUP

The Local Group extends to 10 million light-years from the Sun and is dominated by two large spirals — the Milky Way and M31 in Andromeda. The Milky Way has about 60 satellite galaxies, the largest being the Large Magellanic Cloud and the Small Magellanic Cloud. M31 has its own retinue of three dozen satellites. The vast majority of their satellites are dwarf spheroidals, many discovered within the past two decades.



ESO / DIGITIZED SKY SURVEY 2

▲ **GARLAND OF GLOBULARS** The Milky Way's halo likely formed from smaller galaxies such as the Fornax Dwarf Galaxy. And just as with the Milky Way, six globular clusters also adorn the Fornax Dwarf — an unusually high number for its stellar mass.

have spotted the Sculptor Dwarf in 3- to 4-inch scopes. I'm not surprised — the visibility of dwarf spheroidal galaxies mainly depends on the darkness and transparency of the sky, along with the observer's experience. A large telescope isn't necessarily a requirement.

In the same year that he found the galaxy in Sculptor, Shapley discovered the **Fornax Dwarf**, located 40′ east of 5.8-magnitude Lambda^2 (λ^2) Fornacis. Its brightness is equivalent to an 8th-magnitude star but sprawled over 20′ of celestial real estate. Fornax has a complex star-formation history that includes several episodes of activity. The most recent burst began 1 to 2 billion years ago and continued at a slow pace until ending within the past few million years.

Observing the Fornax Dwarf presents a similar visual challenge as the Sculptor Dwarf, including the galaxy's very low surface brightness and southerly declination. I've only seen it from black skies in the Australian Outback, where the galaxy transits near the zenith. However, my observing friend Akarsh Simha hunted it down during last year's Okie-Tex Star Party at a latitude of 37° north. He glimpsed a large, dim glow hovering at the threshold of visibility through 25×100 binoculars and confirmed it through his 18-inch at 66×.

But there's more to see. A century before the Sculptor Dwarf was found, John Herschel discovered NGC 1049, the brightest of its six globular clusters. A 10- to 12-inch scope shows 12.6-magnitude NGC 1049 as a moderately bright glow with a small, sharp core and a faint 30″ halo. Globulars Fornax 4 and 5 are fainter (magnitude 13.4) with some central brightening, while Fornax 2 is an unconcentrated, hazy patch about 20″ across. The remaining two clusters, Fornax 1 and 6, are challenging targets even for large telescopes.

Leo I and II

In 1950, American astronomers Albert G. Wilson and Robert G. Harrington examined early plates of the *National Geographic-Palomar Observatory Sky Survey* (*POSS*) and discovered **Leo I** and **Leo II**, the third and fourth known dwarf spheroidal galaxies. Leo I is the most distant confirmed Milky Way satellite at 840,000 light-years away. A 2021 kinematic study at the University of Texas's McDonald Observatory found the spread in stellar velocities (called the *velocity dispersion*) steadily increases towards its center. Various models that incorporate these orbits point to an extraordinary black hole of 1 to 5 million solar masses — similar to our Milky Way's black hole — lurking at the dwarf's core. The conclusion is astonishing, since this galactic wimp is roughly 100,000 times less massive than the Milky Way!

Leo I is the easiest dwarf spheroidal to observe, and it's straightforward to locate — aim your scope at first-magnitude Regulus, or Alpha (α) Leonis, and offset 20′ north. But there's the rub. The bright glare from Regulus may overpower Leo I's diaphanous glow. The solution is to choose an eyepiece that shoves Regulus outside the field of view. Leo I will take a higher magnification than other dwarf spheroidals, which often require a low power. At 109× — and with Regulus out of the field — my 8-inch reflector shows a large, dim oval extending 5′ east to west with a subtle central brightening. The galaxy's orientation parallels two 12th-magnitude stars off its northeastern side.

◀ **BLINDING LIGHT** To detect the Leo I Dwarf Galaxy, you'll have to keep Regulus out of your field of view or hide it behind an eyepiece occulting bar. On the other hand, Leo's brightest star makes the galaxy a cinch to locate. This image was acquired with a 4-inch telescope.

BERNHARD HUBL

At a distance of 760,000 light-years, Leo II is the Milky Way's second most remote satellite. It contains populations of both old, metal-deficient stars and intermediate-age stars of higher metallicity. A 2007 photometric study using the 8.2-meter Subaru Telescope on Mauna Kea in Hawaiʻi found star formation occurred galaxy-wide from 8 to 12 billion years ago. It ended first in the outer halo and gradually ceased inwards until halting 4 billion years ago, except at the very center.

To find Leo II, start at 2.6-magnitude Delta (δ) Leonis and slew 1.6° almost due north. Although the directions are straightforward, Leo II is quite challenging to detect. At 108×, my 18-inch Dob shows an extremely diffuse glow spanning 4′ in diameter with no discernible core. A 13.5-magnitude star sits at the center, and a brighter 11th-magnitude star is near the southeastern border.

Draco and Ursa Minor

In 1955, Wilson discovered (always on *POSS* plates) dwarf spheroidals in Ursa Minor and Draco with lower masses and luminosities than any known galaxy. Both objects cover large swaths of sky and glow feebly with an ultra-low surface brightness close to 26.0 magnitudes-per-arcsecond-squared.

A deep photometric study of the **Draco Dwarf** using data from 2004 and 2005 found no signs of tidal tails or asymmetries. The researchers described it as a "flawless dwarf galaxy, featureless and apparently unaffected by Galactic tides." In 2020, Massari and his colleagues published a three-dimensional study of Draco's stellar kinematics

▶ **ETHEREAL SIGHT** You'll have to tease the Ursa Minor Dwarf Galaxy out of the Milky Way's foreground stars (as this image taken with a 24-inch telescope highlights). Use 5.2-magnitude HD 136064 to locate it. The edge-on galaxy west of the star is 14th-magnitude IC 1110.

STEFAN BINNEWIES / JOSEF PÖPSEL

using 81 line-of-sight velocities. By having a larger data set than for the Sculptor Dwarf, they reached a more solid conclusion. The dark matter distribution (cuspy) follows the predictions of popular galaxy formation models.

The Draco Dwarf lies 3.2° northwest of Nu (ν) Draconis, a beautiful binocular pair of 4.9-magnitude stars 62.1″ apart. I most recently observed the galaxy using my 18-inch at 73× from the White Mountains in eastern California (elevation 8,600 feet). I used the locations of two overlying 9th- and 10th-magnitude stars to verify the galaxy's position, but its anemic glow was near my threshold of perception. A helpful trick — tapping the telescope — confirmed the presence of a subtle, slightly elongated brightening. It appeared as much as 15′ in diameter, with indistinct edges that dissolved into the background sky.

To locate the **Ursa Minor Dwarf**, center the 5.2-magnitude star HD 136064, found at the southern end of the constellation, and then shift 0.5° to the west-southwest. Through my 18-inch at 73×, I glimpsed a huge, amorphous glow that barely stood out against the sky background. This ethereal enhancement seemed oval-shaped and covered nearly half of the 1.1° eyepiece field. A 9.4-magnitude star lies just off the southwestern end of the oval, and a 10.8-magnitude star is superposed near its center.

Sagittarius

Astronomers discovered nearby dwarf spheroidals in Carina in 1977 and in Sextans in 1990. But my choice for the Seventh Dwarf is our closest neighbor, the **Sagittarius Dwarf Spheroidal**, which was discovered serendipitously in 1994. The Milky Way is shredding and assimilating its stars — dramatically illustrated by two tidal tails that wrap around our galactic halo. The remnant core of the Sagittarius Dwarf Spheroidal, with the globular cluster M54 marking its center, is hidden behind the Milky Way's central bulge.

Although the galaxy is unobservable (as opposed to just hard!), several of its globular clusters, including Arp 2, Terzan 7, Terzan 8, and Whiting 1, serve as worthy challenges. I covered these and other related objects in the October 2021 issue of *Sky & Telescope* (page 26). The Sagittarius Dwarf Spheroidal is a vivid example of the Milky Way's destructive gravitational grip when a dwarf neighbor wanders too close.

Despite being small and diffuse, dwarf spheroidal galaxies are far more than simple, boring collections of older stars. They are crucial building blocks of today's massive galaxies. And as dark-matter-dominated systems, the Milky Way's nearby surviving dwarfs play a key role in future investigations of the early universe and its evolution.

■ Contributing Editor **STEVE GOTTLIEB** is a fan of galaxies of all sizes. He can be reached at **astrogottlieb@gmail.com**.

RESOURCES: For target finder images go to **https://is.gd/GD_Oct2023**.

Milky Way Dwarfs

Name	Designation	Dist. (k l-y)	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
Sculptor	ESO 351-030	270	24.3	8.6	40′ × 31′	$01^h\ 00.1^m$	–33° 43′
Fornax	ESO 356-004	470	24.0	8.0	17′ × 13′	$02^h\ 40.0^m$	–34° 27′
Leo I	UGC 5470	840	23.3	10.2	10′ × 7.4′	$10^h\ 08.5^m$	+12° 18′
Leo II	UGC 6253	760	24.8	12.0	12′ × 11′	$11^h\ 13.5^m$	+22° 09′
Draco	UGC 10822	250	26.1	10.6	35′ × 24′	$17^h\ 20.2^m$	+57° 55′
Ursa Minor	UGC 9749	250	25.2	10.6	30′ × 19′	$15^h\ 09.2^m$	+67° 13′
Sagittarius	Sgr dSph	80	26.0	3.6	15° × 7°	$18^h\ 55.0^m$	–30° 29′

Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. Surface brightness is in magnitudes-per-arcsecond-squared in the half-light region.

 by Tunç Tezel

Eclipse-Sequence Photography

Here's how to record every stage of an eclipse in one picture.

▲ **ALL IN ONE** Capturing every phase of a solar eclipse in one frame is easier than ever. This composite shows each stage of the hybrid solar eclipse seen from Exmouth, Western Australia, on April 20, 2023. Eclipse chaser Tunç Tezel details his simple technique used to photograph this and many other solar eclipses over nearly a quarter century.

A solar eclipse is among the most fascinating celestial events. It's one of the few times we can witness the motions of the Sun and Moon in real time. Yet eclipses are infrequent and limited to a specific time and set of locations. If you want to experience a total solar eclipse, you have to be positioned within the narrow path of totality. That's where the Moon completely covers the Sun, revealing the corona and prominences and making it possible to experience that otherworldly sensation eclipse chasers often reminisce about for years afterwards.

Naturally, you'll want to photograph the event. There are two methods primarily used to photograph a solar eclipse. The first is to use a long telephoto lens or telescope to zoom in on the eclipsed Sun to resolve prominences and loops and streamers in the corona. The second popular method is to use a wide-angle lens to include the landscape in the spectacle. This approach can show many aspects of the event that you may not be watching for.

As an eclipse chaser myself, I often take both kinds of pictures. Close-ups are wonderful, and a good technique for doing this type of imaging was detailed in the March 2020 issue, beginning on page 30. Yet I'm also a fan of wide-angle views, which capture the experience in a different way. Framing the eclipsed Sun over the location where you witnessed the event adds a personal connection to the photo — one that brings you back to the moment every time you see the picture.

Here's the technique I use to easily capture a composite of the entire event, from partiality to totality and back again, in a single, wide-angle view.

It's All in the Plan

When composing an eclipse-sequence composite, the first thing to consider is that the Sun and Moon are each just ½° across and appear tiny compared to the landscape of your eclipse site. Unless you happen to be located near the beginning or end of the path of totality where the event occurs close to the horizon at either sunrise or sunset, you'll need a very wide-angle lens to ensure each phase of the eclipse falls within a single frame.

Additionally, a total or annular eclipse lasts roughly 2½ hours from first contact to fourth, so you need a wide enough field of view to capture the entire path the Sun traces across the sky during the eclipse to frame it properly. Consider that Earth's rotation carries the Sun across the sky at a speed of about ½° every 2 minutes. That means it will traverse 37½° of sky during the eclipse, so you'll need a lens with a large field of view to accommodate the entire event. Also, the corona can extend several degrees away from the lunar limb in all directions (particularly during solar maximum), so our subject appears much larger and expansive.

Unlike when targeting the inner corona in a close-up image, you don't need complex gear to photograph an eclipse sequence.

Here's what you'll need:

- A camera with a wide-angle lens
- A shutter-release cable or wireless trigger
- A sturdy tripod
- A small piece of solar-filter film

You may notice I haven't recommended a specific camera or lens yet. That's because you can photograph an eclipse sequence with most any digital camera on the market today, provided it has a field that covers at least 50° or so. You can even use the camera in your smartphone or tablet, so long as you have a tripod adapter that can hold it, a wireless trigger, and some control over the exposure.

One device that's very handy is a programmable timer or intervalometer that can trigger exposures at regular intervals. However, this is desirable rather than critical.

The next consideration when planning an eclipse sequence is to carefully select the location where you'll observe and photograph the eclipse. The local times of first contact (when the silhouette of the Moon just begins to bite into the Sun), midpoint of totality, and fourth contact (when the last bit of the Moon exits the solar disk) are critical to know when planning the composition so that you won't have to move your camera partway through the eclipse. The changing altitude and azimuth of the Sun between the beginning and the end of the eclipse will also influence what lens and camera orientation you'll need to come away with a successful sequence of photos you can easily composite together for the finished photo.

For example, if the Sun's altitude doesn't exceed 40° throughout the eclipse, a 24-mm lens paired with a full-frame camera in landscape orientation would comfortably accommodate the sequence with plenty of room to spare. In case of a greater solar altitude, the same 24-mm lens and full-frame camera will also work in portrait orientation as long as the

Lens Field of View

Lens	24x36 mm (full frame)	APS-C (crop sensor)
10 mm	122° × 100°	99° × 76°
14 mm	104° × 81°	80° × 58°
18 mm	90° × 67°	66° × 47°
20 mm	84° × 62°	61° × 43°
24 mm	74° × 53°	52° × 36°
28 mm	66° × 46°	45° × 31°
35 mm	54° × 38°	37° × 25°
50 mm	40° × 27°	26° × 18°

◀▼ **SPLIT VIEW** Solar-filter material is affixed over the top half of the lens (inset) in order to filter the Sun while still allowing the camera to record a properly exposed foreground in the bottom of the frame. This ensures the Sun can be accurately positioned in your final composite, even if the camera is accidentally bumped between individual pictures.

◀▼ **SMARTPHONE SEQUENCING** The half-filter technique can even be used with smartphones or tablets equipped with a good camera. Here the author attached the solar-filter material to the smartphone clamp, making it easy to move out of the camera's view during totality and replace after third contact.

▲ **ASSEMBLING THE RESULTS** Open the base image (or the totality photo) and the first exposure in the sequence in *Adobe Photoshop*. Copy the first exposure and paste it on top of the base image.

Sun isn't higher than, say, 60°, though in this situation it may be better to consider a wider lens, such as a 14-mm, 18-mm, or even a fisheye lens. On the other hand, if the Sun is rising or setting during the eclipse (which shortens the duration of the event), a 35- or 50-mm lens may deliver a nice composition. The choice depends on the local circumstances as well as on the objects you want to include in the foreground. A table showing the coverage offered by several lenses on full-frame and crop-sensor cameras appears on page 61.

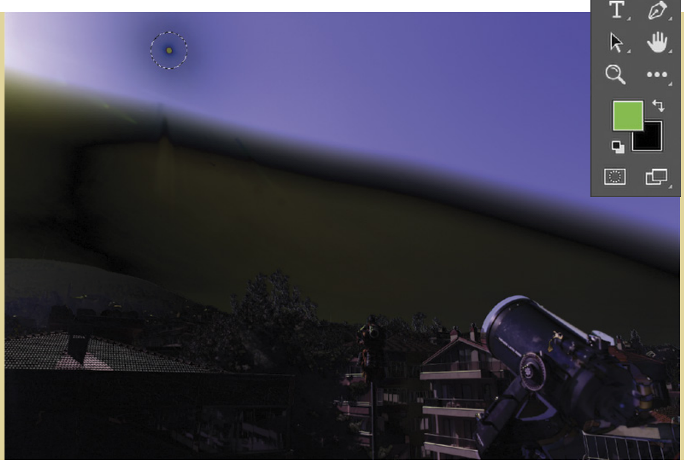
Shooting Strategy

Once you've settled on the specifics of your equipment and composition, the photography itself is straightforward . . . almost. Simply place your camera on your tripod and point it so that the entire eclipse comfortably fits within the frame. Make sure your camera is set to save the photos in its highest-quality format, such as RAW or TIFF. However, you still need a filter to reduce the brightness of the solar disk so that it doesn't appear severely overexposed and bloated in your picture.

Here's an easy trick I use that has an important additional benefit. Use the solar-filter material to cover just the top half of the lens where the Sun appears in the frame. This produces a "split scene" in which the top half of the composition is dark except for the Sun (which is now properly exposed), while the foreground at the bottom of the frame is left unfiltered. I call this the "half-filter method." It has the benefit of including a properly exposed foreground in each picture so that you can easily and accurately align all the partial-phase images later, even if you inadvertently bump the tripod or your camera slowly slips because of a loose tripod connection.

Compared to full-sized digital cameras, the lenses of smartphone cameras are much smaller, so it may be difficult to cover just half. Instead,

▼▶ **A BIG DIFFERENCE** To align the sequence layer to the background image, change the Layer Blending Mode from ***Normal*** to ***Difference***. This highlights any misalignment in the foregrounds of the two layers. Use the Move tool and the arrow keys on your keyboard to nudge the top layer until the bright edges disappear.



▼▶ **SIMPLE SILHOUETTE** Use the Elliptical Selection tool from the Tools window and make a selection around the Sun, leaving plenty of room around the solar limb.

you can simply find a way to hold the filter material a few inches away so that it blocks the Sun in the frame during each shot of the sequence.

The specific choice of filter material will affect your outcome. Typical visual filters and eclipse glasses have an optical density (OD) of 5, filtering all but 0.99999% of incoming light. Such material delivers a solar image that's safe to look at, but the solar disk may be too dark for photography while the unfiltered foreground is properly exposed. A more transmissive filter, such as the Baader Planetarium AstroSolar Photo Film with an OD of 3.8, will produce a well-exposed solar disk with a usable landscape below. It transmits 10× more light compared to OD 5 filters, which means it should be used and stored with caution since it isn't safe for visual use.

Since a solar filter has to be used during the partial phases of the eclipse, you'll also need an unfiltered shot of the sky and foreground to use as the base image that all the other exposures will be composited onto. During this month's annular (or partial) eclipse, you can shoot a separate picture of the foreground before the sequence begins or after it ends, preferably before the Sun enters the frame or after it departs. If you're planning to photograph next April's total solar eclipse, you can capture your base image during totality.

Choosing Intervals Between Photos

The interval between each exposure in a sequence needs to be consistent. While you can manually trip the shutter for each image, timing errors and distractions may lead to gaps and inconsistent spacings in your final composition. This is where a programmable timer or intervalometer helps. You can set it up beforehand to fire the camera at your chosen interval. If you don't have one, you can try setting a series of alarms on your phone to signal when you need to take a photo.

Given that the Sun moves its full diameter every 2 minutes, most sequence photographers use an interval of 4 or 5 minutes. An interval of 2½ minutes, on the other hand, delivers a series of solar disks that nearly touch each other, like pearls on a necklace. The 2½-minute interval is best for partial and annular eclipses but isn't recommended for total eclipses as the phases will interfere with the image of the extended corona in your composite.

Determining when to start the image series is a bit tricky — you need to calculate backwards from the mid-point of totality so that the partial phases are evenly spaced around the totally eclipsed Sun.

When the Moon completely covers the Sun, remove the filter and lengthen your exposure up to a second or two to record the corona. You can also take a few pictures with different exposures in order to make a high-dynamic-range totality frame. Once totality ends, be sure to put the filter back over the top half of the lens to shoot the last hour of partial phases.

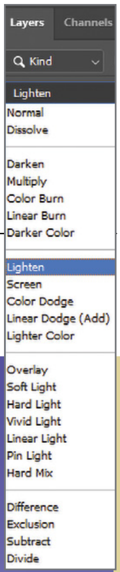
On eclipse day, you'll be taking around 30 to 40 photographs at intervals of 4 or 5 minutes and upwards of 60 frames if you're shooting an annular eclipse at 2½-minute intervals. If the eclipse happens when there's considerable cloud cover, your image sequence might be interrupted, or clouds in your master background frame won't match those in the other frames. In that situation, you may want to photograph a clear sky from the same spot later for your master frame.

You don't need to wait for an eclipse to practice this technique, either — any sunny day will do.

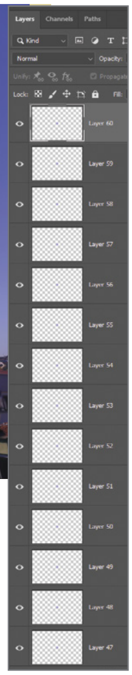
Assembling the Sequence

Putting together the sequence composite is easiest with *Adobe Photoshop*. I suggest first opening the master frame and adjusting it for the desired color balance, brightness, and contrast. Once you're happy with how it looks, save the picture as a TIFF file. Next, open each of the partial-phase photos and process them all in a similar way. With all the phase images open, copy each one

▼ **CUTTING** With the Sun selected, use ***Select* > *Inverse*** from the drop-down menu to select everything you don't want in the layer, then use the backspace key or ***Edit* > *Cut*** to delete the selection.



▼▶ **NATURAL APPEARANCE** Change the Layer Blending Mode from ***Difference*** to ***Lighten*** and the first image in your sequence will be completed and in place in the sky.



▲▶ **RINSE AND REPEAT** Follow the same steps for each sequence photo. This sequence records the partial eclipse visible from Bursa, Turkey, on October 25, 2022.

(***Select*** > ***All, Edit*** > ***Copy***) and paste them as new layers on the master image (***Edit*** > ***Paste***). Be sure the Layers window is open (***Windows*** > ***Layers***). Each of the partial-phase images will show the abrupt split between the filtered Sun half and the unfiltered landscape.

To align these frames, first click on each layer in the Layer window and de-select the "eyeball" to the left of each one to hide them all except the Background and Layer 1. Select Layer 1 and change the layer mode by clicking the arrow to the right of "Normal" and selecting "Difference" from the dropdown menu. This makes misalignments very easy to see. Simply shift layer 1 into alignment by selecting the ***Move*** tool from the Tools palette and nudge the frame using your keyboard arrow keys until the stationary elements in the landscape cancel each other out. If there was some rotation of the camera between frames, you may need to use the ***Transform*** tool to fix it (***Edit*** > ***Transform*** > ***Rotate***).

With the layer now aligned, make a selection around the Sun using the ***Elliptical Marquee*** tool in the Tool palette with ample room around the limb. You may want to feather the edge of the selection, but it isn't necessary. Now invert the selection (***Select*** > ***Inverse***) and delete it (***Edit*** > ***Cut***). Finally, change the layer blending mode from "Difference" to "Lighten" and the first phase of the sequence is in place. Repeat the same procedure for each of the partially eclipsed image layers, and you're pretty much done.

The above shooting technique for creating this kind of photograph is easy and won't distract you from enjoying the show in the sky. The resulting image will be a nice memento of the entire eclipse you can print or share with friends and family.

■ **TUNÇ TEZEL** is a founding member of The World at Night (TWAN) and has traveled all around the world to witness 13 total and 3 annular solar eclipses.

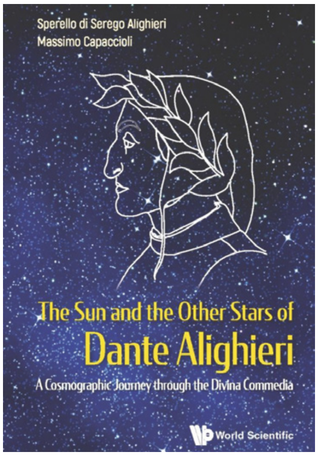
SETTING FOR OPPORTUNITY The annular eclipse of May 20, 2012 is shown setting over Monument Valley Navajo Tribal Park along the Arizona and Utah border. Setting or rising eclipses offer an opportunity to use longer lenses for greater detail thanks to the shorter length of the event. You can photograph this month's annular eclipse from Monument Valley in a similar way if you position yourself at the Navajo Campground. See page 34 for our preview of the October 14th event.

Dante on Astronomy

THE SUN AND THE OTHER STARS OF DANTE ALIGHIERI:

A Cosmographic Journey Through the Divina Commedia

Sperello di Serego Alighieri and Massimo Capaccioli
World Scientific Publishing Co., 2022
180 pages, ISBN 978-981-124-549-7
US$58.00, hardcover



REFERENCES TO ASTRONOMY abound in Dante Alighieri's *The Divine Comedy*. Dante assumed his readers understood them — people in his day were more familiar with the skies than we are today, in part because they had to rely on the stars and their feeble light for traveling at night. Sperello di Serego Alighieri, an astrophysicist and direct descendant of Dante (19th generation after the poet), and Massimo Capaccioli, a top Italian astronomer, wrote *The Sun and the Other Stars of Dante Alighieri* to explicate those astronomical references within the context of the cosmological knowledge of Dante's time.

Dante (1265–1321) set his fictional journey through Hell, purgatory, and paradise (the narrative poem's *Inferno*, *Purgatorio*, and *Paradiso*) within an Earth-centered cosmological model. He located Hell at the core of our planet and envisaged purgatory as a mountain located on the opposite side of the globe from where his journey began. (Dante made himself a character in his own story.) He imagined the different levels of paradise to comprise the heavenly bodies — the Sun, the Moon, and the planets out to Saturn — revolving around Earth along with the fixed stars. The journey ended at the highest level of paradise, the Empyrean, a heaven of pure light lying beyond the stars at the edge of the universe.

Despite living at a time when people thought the Sun lay at the center of the universe, and despite espousing the medieval view that did not distinguish astronomy from astrology (the authors devote a chapter to this topic), Dante actually got much of the science right.

For instance, in *Purgatorio* the poet correctly attributes the appearance of rainbows to refraction of solar rays in raindrops: "And just as the air, when it is very moist, becomes adorned with various colors because it reflects another's rays . . ." Dante also, in *Paradiso,* accurately explains the tides: "And as the turning of the heaven of the moon covers and uncovers the shores without pause, so Fortune does with Florence."

Even when referring to the darkness that the Gospels say fell as Christ hung on the cross, Dante alluded to the fact that solar eclipses happen during new Moon rather than full Moon. Hence, the twilight that scripture says descended as Christ died — which occurred during full Moon — was, Dante claims in *Paradiso*, an extraordinary phenomenon: "One says the Moon turned back during Christ's passion and interposed itself so that the light of the Sun could not reach the Earth."

The dialogue that Dante the character has with Beatrice, his guide from the end of *Purgatorio* through *Paradiso*, on what created the "spots" on the Moon serves as a masterful scientific treatise. Beatrice corrects Dante's notion that differences in density of lunar matter cause the dark regions we now call *maria* to stand out from lighter-colored areas of the Moon. After walking Dante through thought experiments (which remind one of what Einstein did so famously six centuries later), Beatrice explains the causes of the Moon's color differences. They arise, she says, from the "virtue" that the Empyrean distributes — in other words, from the different degrees that various substances reflect light. Indeed, as we know today, the Moon's dark maria consist of basalt, which reflects light less than the more reflective anorthosite in the lunar highlands.

The authors discuss the state of astronomy before Dante as well as the date and time in which *The Divine Comedy* was set based on his descriptions of the sky. They also delve into parallel universes, the planets and stars, and the mysteries of the Milky Way. Altogether the book is a fascinating peek into the state of medieval astronomy, which, despite its errors, was more sophisticated than we moderns give it credit for. As such, the book is a valuable resource on the history of astronomy.

The Sun and the Other Stars of Dante Alighieri is somewhat technical, but astronomy enthusiasts interested in Dante, Dante enthusiasts curious about astronomy, and anyone fascinated by medieval astronomy will love the book.

■ **CRISTINA MONTES** is an attorney, law professor, and writer based in Manila, the Philippines. Her Focal Point "From Street to Streaming" ran in the July 2022 issue, p. 84.

SBIG's STC-7 CMOS Camera

This camera package will appeal to those with an interest in advanced imaging capabilities.

FOR MORE THAN 30 YEARS Santa Barbara Instrument Group — a company born in sunny California and better known by its acronym SBIG — has been a pioneer in developing advanced imaging equipment targeted for the amateur community. Now owned by the Canadian firm Diffraction Limited, SBIG's latest offerings include the STC-7, a cooled, monochrome astronomical CMOS camera capable of advanced imaging projects and collecting scientific data. But it's also easy enough to use to appeal to someone just getting started with astrophotography.

The STC-7 is sold as a complete package that's ready to connect to your telescope and computer. The camera has a built-in, 8-position filter wheel and comes with seven filters for broadband and narrowband imaging. You also get a power supply that runs off AC house current, all required cables, and a 2-inch nosepiece that threads into the camera body's T-thread opening.

◀ The STC-7 package comes with everything shown here, including a 3-meter-long (10-foot-long) USB 3.0 cable and an AC power supply with an extension cable that totals 5 meters. The camera is also USB 2.0-compatible, which allows for longer cable runs at the expense of slower download speeds.

Rounding out the package is a "lite" version of Diffraction Limited's flagship, Windows-based *MaxIm* camera-control and image-processing software (*MaxIm LT*), and a hard carrying case.

For shooting traditional color images there are luminance, red, green, and blue filters. For creating narrowband-color images with the so-called Hubble palette there are H-alpha, OIII, and SII narrowband filters. The filter wheel's eighth position is typically fitted with a supplied opaque "filter" used for shooting dark frames. (The camera does not have a traditional mechanical shutter.)

At the heart of the STC-7 is Sony's third-generation, 7-megapixel IMX-428 CMOS sensor with 4.5-micron pixels in a 14.4-by-9.9-mm array. Compared with the KAF-8300 CCD sensor that was extremely popular in astronomical cameras when the digital-imaging industry began transitioning to CMOS detectors, the IMX-428 has "higher sensitivity, lower read noise, and a much faster readout" according to Diffraction Limited. For deep-sky imaging, the sensor is well matched for telescopes with focal lengths between 500 and 1,000 mm, making it a good fit for many of the small astrographs popular with imagers these days.

▲ *Left:* The internal 8-position filter wheel uses its eighth slot for an opaque "filter" that serves as a shutter when taking dark frames. *Right:* Although the STC-7's sensor has a total imaging area only one-sixth that of a full-frame DSLR camera, its 4.5-micron pixels are similar in size to those in high-end cameras like the Nikon D850 pictured here, making the STC-7 an attractive camera for astrophotography done with conventional camera lenses.

SBIG STC-7

U.S. Price: currently reduced to $3,499
diffractionlimited.com

What We Like

Complete package for advanced imaging

Highly sensitive, low-noise CMOS detector

SBIG's reputation for supporting the amateur community

What We Don't Like

Unusual power connector will require a custom cable for working with 12v batteries in the field

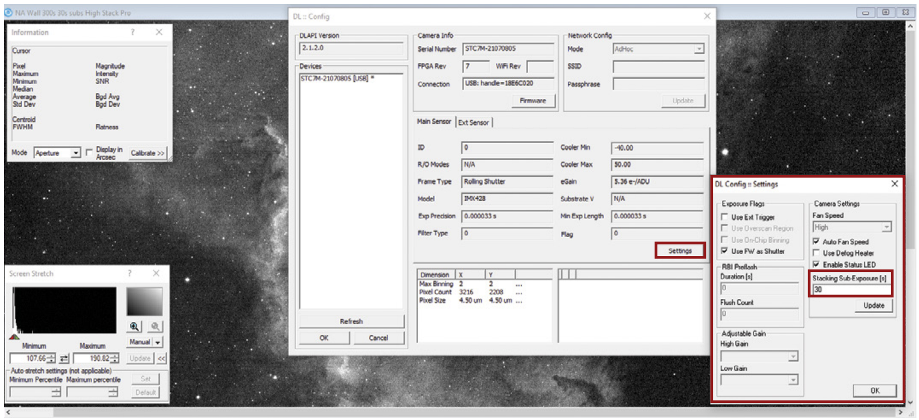
MaxIm LT supports image readout from the STC-7 at three selectable gain modes. (Details of these modes showing the gain, full-well capacity, and read noise are available on the company's website.) Each of these gain modes produces a 12-bit image. While the advantages of using different gain settings are beyond the scope of this review, they are used to optimize exposures depending on observing conditions and the intended imaging goals, including things like measuring star brightness and/or capturing faint nebulosity.

The camera includes a powerful feature called Stack Pro that automatically divides a given exposure duration into as many as 16 individual frames that are stacked within the camera and read out as a single image. The internal process happens so fast that from the outside it's virtually indistinguishable from a single exposure of a set duration (something that tripped me up during my early camera tests, but for now just hold that thought). Stack Pro has the important advantage of producing 16-bit images. While the technique of capturing many short CMOS images and stacking them with software is a common practice among today's astrophotographers, the fact Stack Pro does this automatically within the camera and reads out as a single image saves a huge amount of computer storage space and time later spent processing images.

Before Heading Outside

The only things you have to do to initially get the STC-7 ready for imaging is install the filters in the filter wheel and load the software and appropriate drivers on your computer. Installing the filters should be done carefully in a clean environment to avoid getting dust on them and especially on the CMOS chamber window since it is not readily accessible for cleaning after the filters are in place. I suggest having plenty of bright light, a lens brush, compressed air or a dust blower, and a pair of tweezers for handling small screws when doing the work.

Because I've been controlling many different CCD cameras with the full

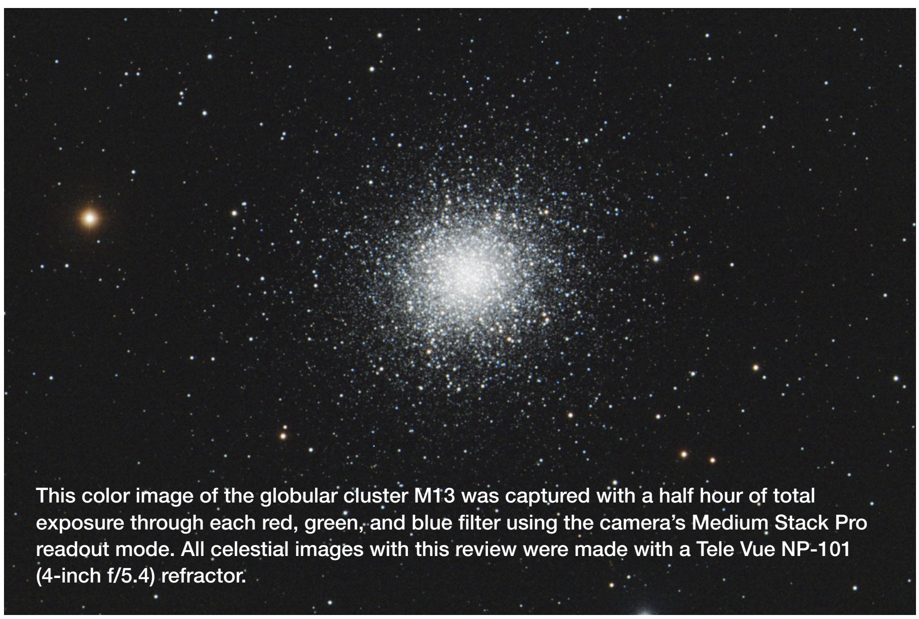


▲ As explained in the accompanying text, the author's overconfidence using *MaxIm DL* software initially caused him to overlook the important dialog box at far right (accessed via the ***Settings*** button in the large dialog box), where you set a value for the minimum duration of subexposures used for the STC-7's powerful Stack Pro feature.

version of *MaxIm DL* for decades, I didn't install the lite version shipped with the STC-7, but I did need to make sure my software running on a Windows 10 laptop was updated to the latest version (*MaxIm DL Pro* version 6.29). Using my own version of *MaxIm DL* meant I still needed to install the camera drivers — something that happens automatically when you install the lite version supplied on a USB thumb drive. I'm not enough of a computer jockey to be confident which were the right driver files buried in the directories on the thumb drive and where to copy them on my computer. The information for installing the drivers manually wasn't in the manual, so I contacted customer support at Diffraction Limited and was quickly walked through the relatively simple process (the details for doing it have since been added to the user's manual). Once this was done it was time for me to head to the telescope.

Under the Stars

For my first imaging sessions I decided beforehand to shoot RGB images of galaxies in the springtime sky using 5-minute exposures with the Stack Pro feature at the medium gain setting. The very first image out of the camera looked great, so I was off to a good start collect-



This color image of the globular cluster M13 was captured with a half hour of total exposure through each red, green, and blue filter using the camera's Medium Stack Pro readout mode. All celestial images with this review were made with a Tele Vue NP-101 (4-inch f/5.4) refractor.

ing several nights of data. It wasn't until several days later that I began looking at the data in detail and realized something wasn't right: These were not the 16-bit images I was expecting.

Generally, I don't take the time and space in reviews to write about screwups that are my own fault (there are too many of them). But this one is worthy of an exception because some of the problem stemmed from my years of experience using *MaxIm DL,* and I know there are a lot of others like me, so my tale may serve as a cautionary word for others.

Because I was shooting with the Stack Pro feature, I expected my 5-minute exposures to actually be stacks of 16 short exposures (in this case each about 19 seconds long) automatically stacked in the camera and read out as single images. And, as I mentioned earlier, the stacking process happens so fast I knew that my 5-minute exposures would essentially take 5 minutes since there's no noticeable overhead associated with the stacking process.

I also knew that there are fundamental advantages to making individual deep-sky exposures that are as long as sky conditions permit. This is mentioned in the STC-7 manual, and accordingly there's a place in the camera setup within *MaxIm DL* that lets you specify the minimum length of the subexposures used by Stack Pro even if it results in less than 16 stacked frames in the final image. For example, a minimum subexposure of 30 seconds would create a stack of 10 rather than 16 frames for a 5-minute image. For my early tests, however, I was simply letting the camera make 16-frame stacks before experimenting with longer subexposures.

▲ While the STC-7 does not shoot video, it can save very rapid sequences of individual frames. This view of the Moon was captured last June 22nd more than 90 minutes before sunset. Thirty 0.07-second exposures through an H-alpha filter (used to darken the sky) were recorded in less than 45 seconds and combined to produce the final image.

In hindsight, when first I got to the telescope and connected the camera to *MaxIm DL*, it was my experience with the software that misled me into thinking I'd easily understand all the settings. But I mistakenly interpreted one as being the minimum subexposure length for Stack Pro. The correct place to set this value was in another dialog box that I skipped over (and, more importantly, the value was set to 3,600 seconds by default).

This meant that all of my Stack Pro images were just single exposures, because the 3,600-second minimum subexposure was longer than the total exposure time I had requested for my images. Obviously, the error was mine and in part was due to my overconfidence with using *MaxIm DL* — a new user might have been more diligent about exploring the dialog box that I overlooked. And my error negated the advantages I was expecting from using Stack Pro. After I properly set my subexposure duration, it was smooth sailing on future nights.

Diffraction Limited states that the camera's fan-assisted, two-stage thermoelectric cooler can drop the sensor temperature by "approximately 30°C" from ambient air temperature, though I found it a safer bet to not ask for more than 25°C of cooling, especially on warm nights. Even with minimal cooling, however, the CMOS chip has a very low dark current and produces clean images with only a minor sprinkling of hot pixels visible before calibration.

The camera's regulated cooler typically holds the set temperature to an accuracy of 0.1°C. As such, I was able to make a library of dark calibration frames that were useful over many nights, as long as I always ran the camera at the same temperature.

People like me with a long history of working with CCD cameras will find a few changes in the procedures for calibrating images made with the STC-7 because of its CMOS detector. The user manual has a detailed section on image calibration, and I suggest that even those with extensive CCD experience read through it.

One of the differences from CCD

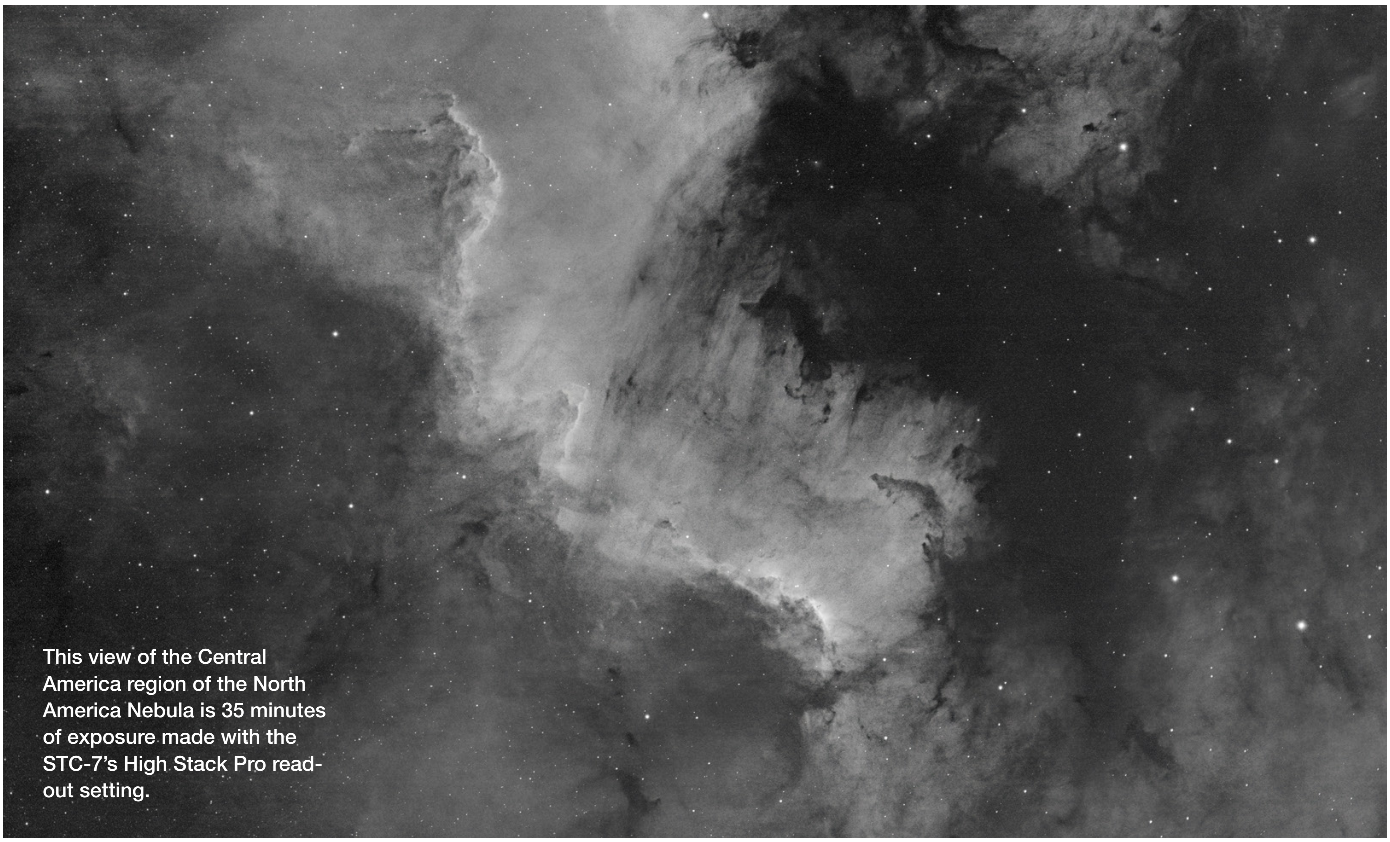
▲ Despite thick smoke from Canadian wildfires blanketing New England, the author recorded this view of the galaxy M101 sporting an 11th-magnitude supernova (arrowed) on the night of last May 26th. The LRGB image was assembled from 35 minutes of total exposure through each filter.

▲ All the other deep-sky images with this review were assembled from groups of 5-minute exposures made with the STC-7's Stack Pro feature set for a minimum subexposure duration of 30 seconds. These views of the Whirlpool Galaxy, M51, are just single 5-minute Stack Pro exposures all processed identically and made with (left to right) low-, medium-, and high-gain readout modes.

calibration that's noteworthy is that Diffraction Limited does not recommend using separate bias frames in the calibration process, relying instead on the inherent bias data that exist in dark and flat-field frames. Most important, however, is that calibration frames must be made using the same readout mode as the light frames they are used to calibrate. It's also stated that dark frames be made with the same exposure duration as the light frames — there's no mention of dark-frame scaling, which I'm pretty sure is intentional.

The STC-7 was my second extensive use of a cooled CMOS camera, and I came away highly impressed with its capabilities. Despite its advanced features, the learning curve is modest, and it shouldn't take long for even those new to digital imaging to get up to speed. I also like that the camera is sold as a complete package that has no hidden costs associated with getting started. Once again SBIG has set a standard for those entering the world of astrophotography.

■ **DENNIS DI CICCO** finds it hard to believe that the years he's been doing digital astrophotography have now surpassed the three decades he previously spent shooting with film.



This view of the Central America region of the North America Nebula is 35 minutes of exposure made with the STC-7's High Stack Pro readout setting.

◀ ELECTRONIC FOCUSER

iOptron introduces an electronic focuser accessory for astrophotographers. The iOptron Electronic Automatic Focuser ($218) is designed to connect to both Crayford and rack-and-pinion focusers. The iEAF is ASCOM-compliant and is compatible with most astro-imaging software. The unit connects to your computer via an included 2-meter USB 2.0 cable and can also be manually driven using the two buttons located adjacent to the cable port. The device recalls its position after each power cycle, and it also includes an internal temperature sensor that works with advanced imaging programs to automatically adjust focus as the temperature drops and your telescope changes focus. The device is powered through its USB connection and includes a universal mounting bracket, an assortment of hex wrenches, and additional hardware for coupling to a variety of focusers.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

◀ OBSERVING STATION

Chinese manufacturer ZWO unveils its first entry into the "smart telescope" market with the Seestar S50 ($499). The device is built around a 50-mm f/5 apochromatic triplet refractor paired with a Sony IMX462 CMOS color camera having a 1,920 × 1,080 array of 2.9-micron-square pixels. The optics and internal electronics ride along in a compact, alt-azimuth Go To mount weighing 2.5 kilograms (5.5 pounds) in all. The Seestar S50 is controlled with a smartphone or tablet using the ASIAIR app and connects with either Wi-Fi or Bluetooth. Images are saved on 64GB of internal memory. The device is powered by an internal, rechargeable lithium-ion battery that can run the unit for up to 6 hours. Each purchase includes a field tripod, USB-C charging cable, lens cap, and soft case.

ZWO
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: 0-51265923102; zwoastro.com

◀ TINY ASTROGRAPH

William Optics announces a new addition to its extensive line of wide-field astrographs. The Cat61 WIFD APO 300mm f/4.9 ($1,598) is a 4-element, 61-mm Petzval refractor that utilizes FPL-53 extra-dispersion glass to produce sharp, color-free stars across a 45-mm fully corrected image circle. The telescope weighs 2.5 kg and features an internal, dual-speed, rack-and-pinion focuser with tilt adapter. Also included are a Vixen-style mounting bar, a saddle-handle bar that accepts Synta-style removable finder brackets, a Bahtinov focusing mask with aluminum lens cover, and a soft carrying case.

William Optics
williamoptics.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.

That Crucial Extra Step

Modifying your ladder can make for much more pleasant observing.

THOSE OF US with big and/or long-focal-ratio Dobsonians are intimately familiar with one of the banes of amateur astronomy: ladders. Climbing up a set of steps in the dark in order to peer into an eyepiece several feet overhead can be scary, and moving the ladder around to a new observing position can be a clumsy, frustrating endeavor, especially on uneven ground. Dislike of ladders has spurred an entire movement toward faster telescopes, such as Mel Bartels's 25-inch f/2.6 (*S&T:* Feb. 2019, p. 70) that he can look through at zenith with his feet flat on the ground.

Extremely fast telescopes aren't for everyone, though, and there are still a lot of big, tall scopes out there. Some of us buy them from people who move on to those faster scopes, and we suddenly find ourselves in need of a good ladder. Others have simply endured bad ladders for years (I speak from experience here). But we don't have to do that. Author, ATM, and former editor of *Astronomy* magazine Richard Berry recently said to me, "If we invested one-tenth the effort designing a good ladder as we do trying to figure faster mirrors . . ." He left the rest unsaid because it was so obvious.

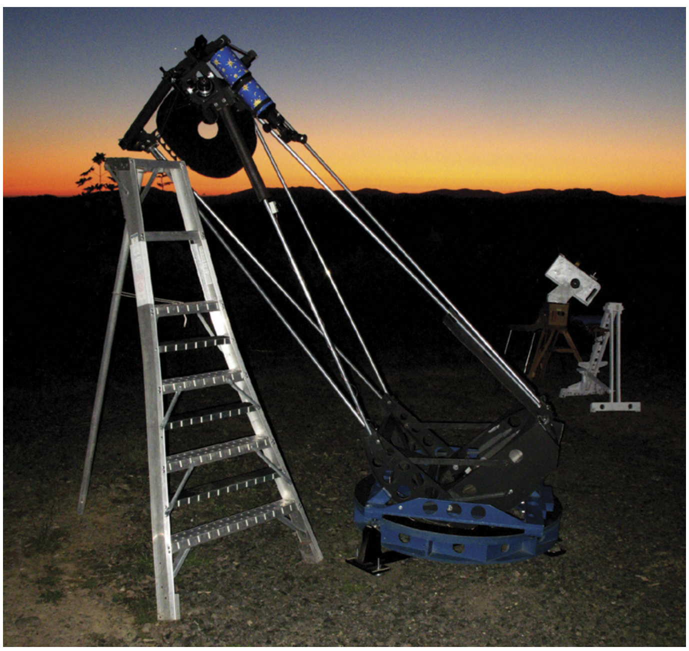
What makes a good astronomy ladder? The number of legs, for one. Unless you're observing on a flat surface like a parking lot or a lawn, a four-legged stepladder will rock on the two legs that rest on the highest ground. That's not something you want happening when you're four feet in the air in the dark. A three-legged ladder — often called an orchard ladder — is stable even on bumpy ground. And orchard ladders usually have a very wide stance in front, making them even more steady.

Weight is another crucial factor. A heavy ladder tires you out long before the night is over. Aluminum ladders are good, and fiberglass ladders are even better. A fiberglass ladder has one other advantage: It's warmer on your hands on cold nights.

Perhaps the most significant feature on a truly good astronomy ladder, though, is the spacing of the steps. Most ladders have steps every 12 inches, and that's just too far apart for comfort. Half the time you're either stretching up or scrunching down to reach the eyepiece, and in the dark those one-foot gaps can feel awfully daunting on the way down.

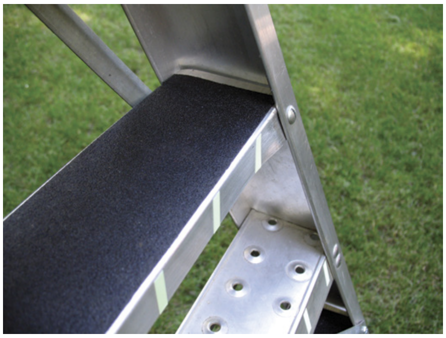
Fortunately, it's relatively easy to add intermediate steps. My old four-legged stepladder had three deep steps, so I made extras out of wood, and they just rested on the steps below them. But wood stout enough to bear significant weight is heavy, and my ladder was already a hefty 25 pounds (11.3 kilograms). With extra steps it was 33. Plus, its four legs made it wobbly on any but the flattest ground.

Richard's comment got me to thinking about alternatives, so when I found a six-foot (1.8-meter) orchard ladder at a garage sale, I snapped it up. A trip to a local metal dealer provided three lengths of ⅛-inch-thick channel aluminum the same width (three inches) as the steps and an inch high,



▲ *Left:* An orchard ladder with extra steps serves as an ideal astronomy ladder. *Right:* Glow-in-the-dark tape makes finding the steps easy even under an extremely dark sky.

ALL IMAGES COURTESY OF THE AUTHOR



▲ *Top:* Additional steps can be made of channel aluminum. The edges will have to be bent to match the angle of the ladder. *Bottom:* The angle bends on the ends of the extra steps help align them with the factory steps.

plenty strong enough to span even the wide gap above the bottommost step. I had to cut the ends at the same angle as the ladder's sides and bend the outer couple inches of the walls to match the tilt of the other steps, but a simple hacksaw made the cuts, and a big crescent wrench did the bending. I drilled and bolted the steps in place, put some rough tread material on the smooth aluminum tops to provide some grip, added some glow-in-the-dark tape to make the steps easy to find in the dark, and that was my ladder.

My first night out with it was a delight. I felt like I had a new telescope, not just a new ladder. My 20-inch f/5 Tri-Dob was a joy to slew from target to target anywhere in the sky because the ladder was so easy to position, and it was rock steady every time.

But my hands grew cold holding onto the aluminum sides when I moved it. That suggested one final mod: insulating the area that I grab with closed-cell foam. Now I've got a dream ladder that makes observing with a big scope as pleasant as I could ask for.

■ Contributing Editor **JERRY OLTION** likes tall scopes. They make him feel like he's doing some serious observing.

What Is an Aurora?

NOT MANY CELESTIAL PHENOMENA are so grand that they light up big sections of the night sky. Aurorae win the gold here. These sweeping curtains of light can festoon the heavens, gleaming in green tinged with red, purple, and other colors.

Aurorae appear primarily at high latitudes, along an *auroral oval* that rings each of our planet's geomagnetic poles. In the Northern Hemisphere, the auroral zone includes Alaska, Canada, Greenland, Iceland, Scandinavia, and Siberia. In the Southern Hemisphere, it makes a loop above Antarctica.

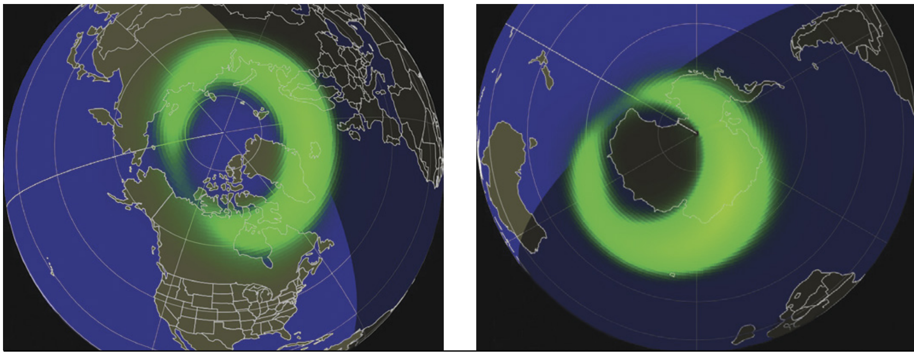
We can thank the Sun and our planet's magnetic field for aurorae. Every second, roughly 1 million tons of charged particles leave the Sun in what's called the *solar wind*. These gusts blow through the solar system, carrying with them our star's magnetic field.

When the solar wind reaches Earth, it buffets our planet's magnetic bubble, the *magnetosphere*. Impeded, the solar wind slides around the magnetosphere and shapes it into a round-nosed windsock, with the tail streaming out behind our planet's nightside.

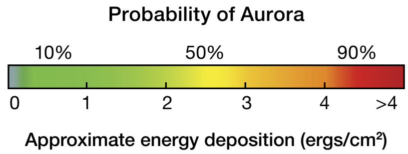
But Earth's magnetic field doesn't fully shield us from the wind. The poles are the field's weak points. The field lines trace big loops, exiting one pole and entering the other one. Solar-wind particles can sneak through here, traveling down the magnetic lines to rain on Earth's upper atmosphere. There, they collide with atoms and molecules. Chemically startled, the atoms and molecules emit light to calm back down. The result is a diffuse aurora.

▲ **ALASKAN LIGHTS** Aurorae bedazzled the night sky on March 24, 2023, northeast of Fairbanks, Alaska. *S&T* online gallery contributor Bruce Gottlieb took this image with a Nikon D750 camera and Sigma 14-24 mm Art lens.

But sometimes the Sun throws a snit fit. At these times, our star hurls a blast of plasma, called a *coronal mass ejection* (CME), into interplanetary space. If aimed just right, the CME can hit us



◀ **FORECAST** Based on the solar wind's speed and the properties of the magnetic field it carries, researchers can forecast how likely aurorae are and where they'll appear. (These are for May 8, 2023.) NOAA provides predictions for the next hour, tonight, and tomorrow.



and trigger a *geomagnetic storm* — the space equivalent of bad weather.

But in order to break through, the CME particles need Earth's magnetic field to let them in. This can happen if the CME-carried magnetic field and our planet's field are oriented to each other in the right way, enabling them to link up in a process called *magnetic reconnection*. The field lines will snap together in a new arrangement, releasing energy and opening the magnetic door.

Earth's field then shuttles the invaders to the planet's nightside, where they cause part of the windsock's tail to pinch off. The pinch makes a loop that snaps back toward Earth, sending particles zooming toward the poles. Large sheets of electric current speed them up, and they smash into the upper atmosphere.

During these storms, the auroral oval greatly expands. Aurorae may appear as far from the poles as Florida and central Australia.

Painting the Sky

Aurorae appear as shimmering curtains, arcs, bands, and swirls. A display can last for tens of minutes or even the entire night, sometimes rapidly changing its appearance. The interaction of electric currents and the magnetic field creates these patterns. You may also see towering rays, which trace the magnetic field lines the particles traveled along to reach the atmosphere.

An aurora's colors depend on what the charged particles hit in the atmosphere and how high up those particles are. The characteristic green color comes from oxygen, roughly 100 to 110 kilometers (60 to 70 miles) high. At lower altitudes, air is so dense that an oxygen atom will lose its energy by colliding with another atom before it can emit a green photon.

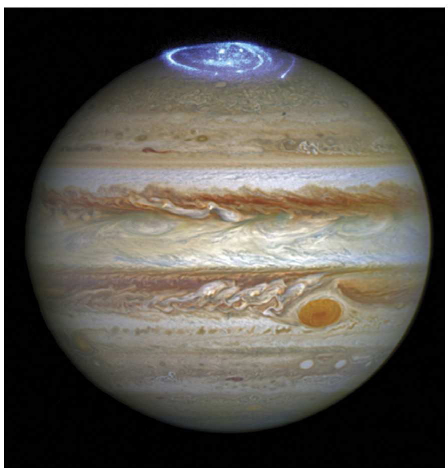
Deep red also comes from oxygen, but at much higher altitudes — we're talking 200 or 300 km and up. Oxygen atoms take much longer to emit this red glow than they do the green one, so they only have time to do so up here where the air is super-thin.

Other reds, blues, and purples can come from molecular nitrogen.

Pack Your Bags

The best time of year to see an aurora is typically around the spring and fall equinoxes, when the magnetic fields of Earth and the solar wind align in such a way that reconnection is more likely to happen. (This is why we run *S&T*'s aurora tours in the spring and fall.)

Because more people live beneath the northern auroral oval than the southern one, many of us are more familiar with the Northern Hemisphere version, called the *aurora borealis* or northern lights, than its southern counterpart, the *aurora australis*. But the Southern Hemisphere isn't entirely out of luck: For example, on a clear night Tasmania has on average a 1% or 2% chance of seeing the southern lights.



▲ **JUPITER'S AURORA** This composite image combines ultraviolet observations (blue) with visible-light ones to show the aurora on the solar system's largest planet.

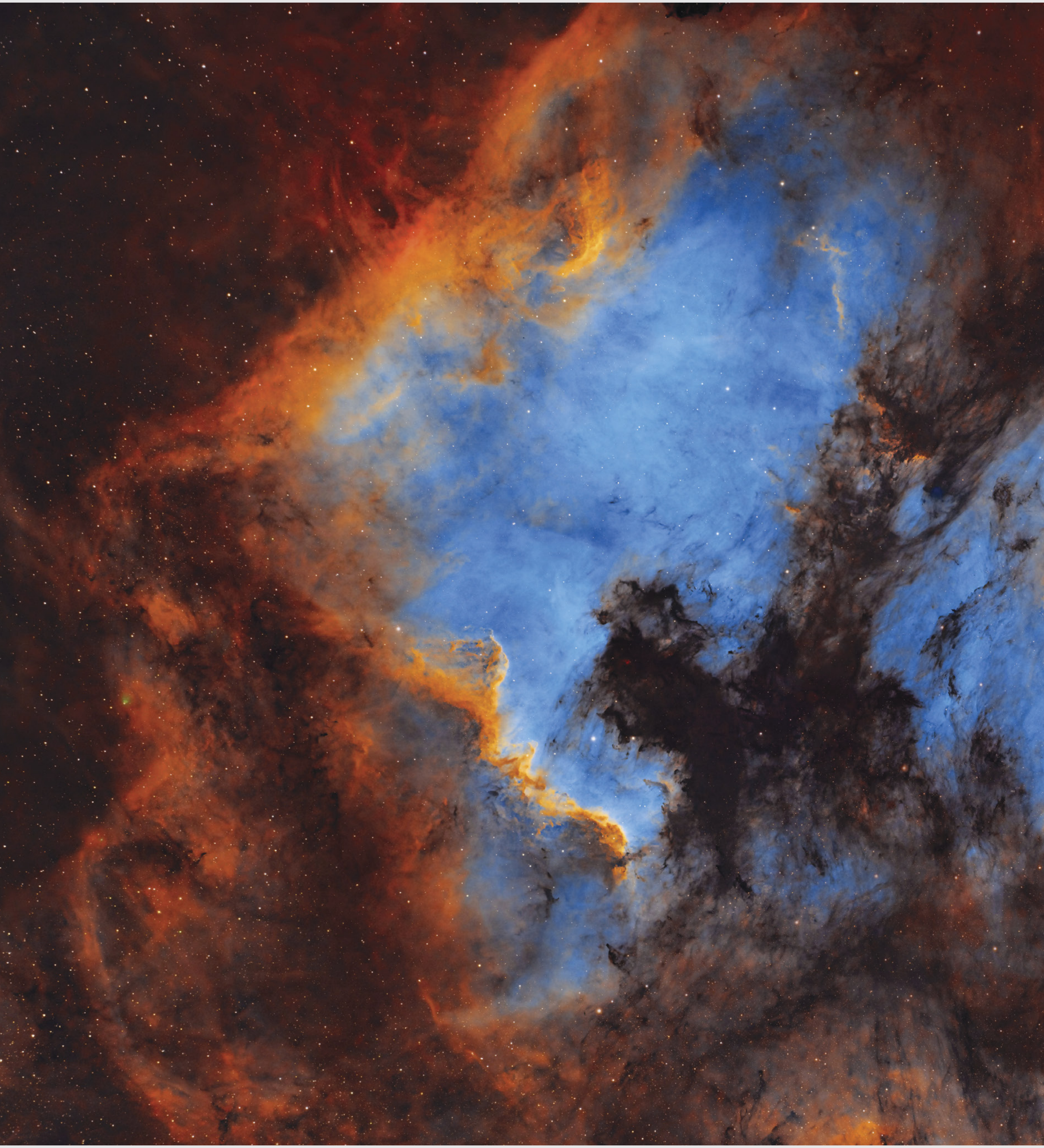
Alien Aurorae?

Aurorae also appear on nearly every planet in the solar system (poor Mercury being the odd one out). Jupiter has the most powerful, thanks to a magnetic field that's some 20,000 times stronger than Earth's. Most of the charged particles that fuel Jupiter's aurora come from its big moons, particularly the volcanic moon Io. The moons actually leave auroral footprints in Jupiter's atmosphere, glowing dots that mark where the current from each moon hits the planet. The moons also have their own aurorae.

Martian aurorae look quite different than ours, because the planet doesn't have a global magnetic field. Diffuse aurorae can cover the whole night sky, as charged particles rain down into the atmosphere without magnetic guidance. Mars also has localized aurorae, the brightest of which appear above places where the planet's long-gone global field left its imprint in the crust. Such aurorae tend to happen in the evening hours. They might even be visible to future astronauts on the surface. ■

Find the latest space-weather forecast from the National Oceanic and Atmospheric Administration: https://is.gd/noaa_aurora.

AURORA FORECAST FOR BOTH HEMISPHERES: NOAA SPACE WEATHER PREDICTION CENTER (2); JUPITER AURORA: NASA / ESA / J. NICHOLS (UNIVERSITY OF LEICESTER), ACKNOWLEDGMENT: A. SIMON (NASA / GSFC) AND THE OPAL TEAM



◁ NEBULOUS NORTH AMERICA

Harshwardhan Pathak

Emission nebula NGC 7000 (left) in Cygnus bears a striking resemblance to the earthly continent. To its right, the Pelican Nebula (IC 5070 and 5067) is actually part of the same star-forming region, but the dark column of dust designated LDN 935 at center separates the two and provides the distinctive shape of the Gulf of Mexico.

DETAILS: *Takahashi FSQ-106EDX4 refractor at f/3.6 and QHY600M Pro camera. Total exposure: 2⅙ hours through narrowband filters.*

▽ ELEPHANT'S TRUNK

Daniel Beaulieu

Cometary globule vdB 142 is a dark column of dust and gas located within the larger emission nebula IC 1396 some 3,000 light-years away in the constellation Cepheus.

DETAILS: *iOptron Photron Ritchey-Chrétien and ZWO ASI2600MM Pro camera. Total exposure: 4.4 hours through narrowband filters.*

◁ STELLAR TRIAD

Drew Evans

Rho Ophiuchi is a star system in Ophiuchus with three major parts: the binary star ρ Oph AB (center), the nearby variable ρ Oph C (right), and the smaller binary ρ Oph DE (below). They're nestled in the bluish reflection nebula IC 4604. North is to the right.

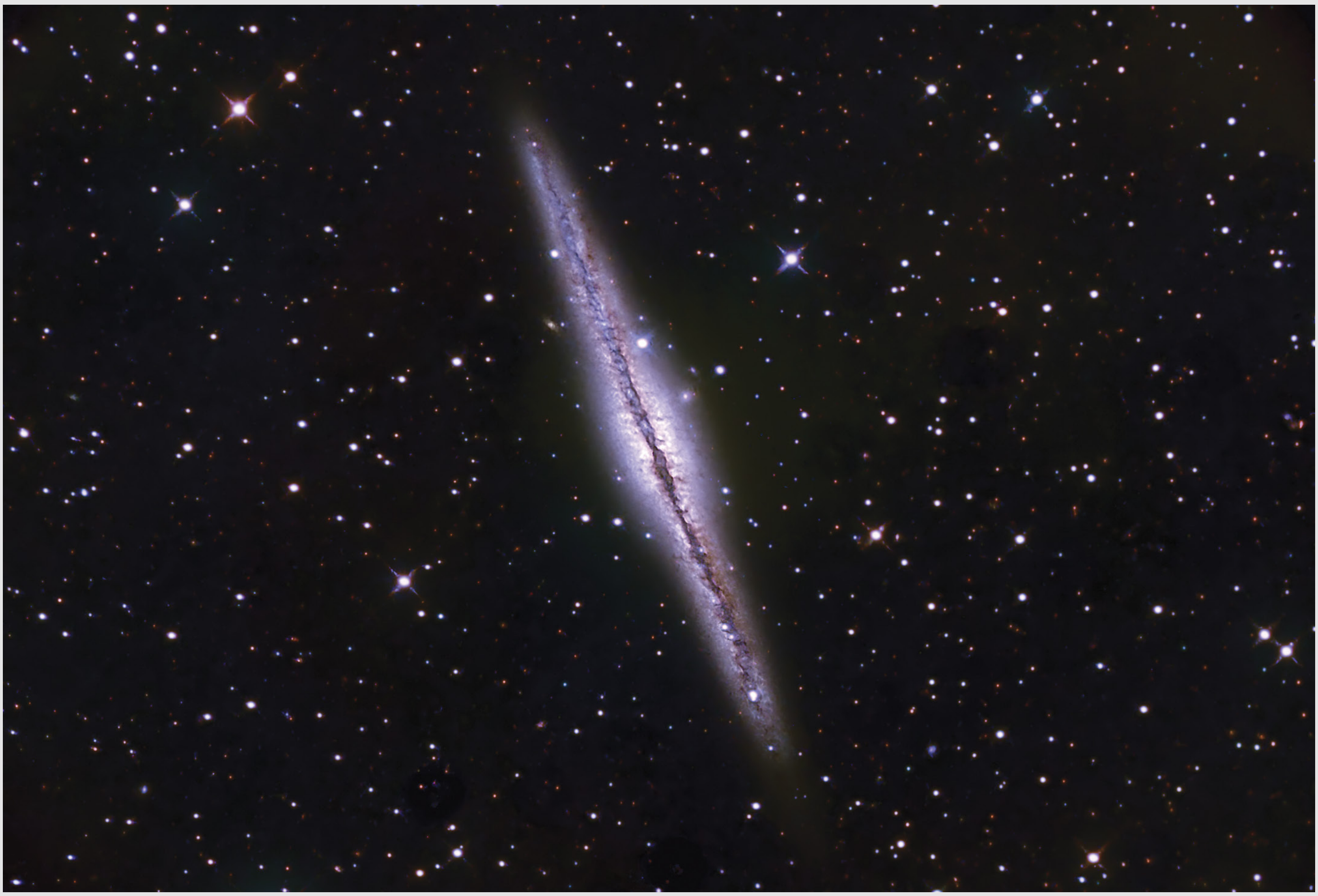
DETAILS: *Sharpstar SCA260 f/5 Cassegrain astrograph and ZWO ASI2600MM Pro camera. Total exposure: 5.6 hours through LRGB filters.*

▽ SILVER SLIVER GALAXY

Mario Motta

Nearly 30 million light-years away in Andromeda lies the edge-on spiral galaxy NGC 891. It boasts a complex dust lane and bright central bulge.

DETAILS: *Handmade 32-inch reflector and ZWO ASI6200 camera. Total exposure: 4 hours through LRGB and Hα filters.*



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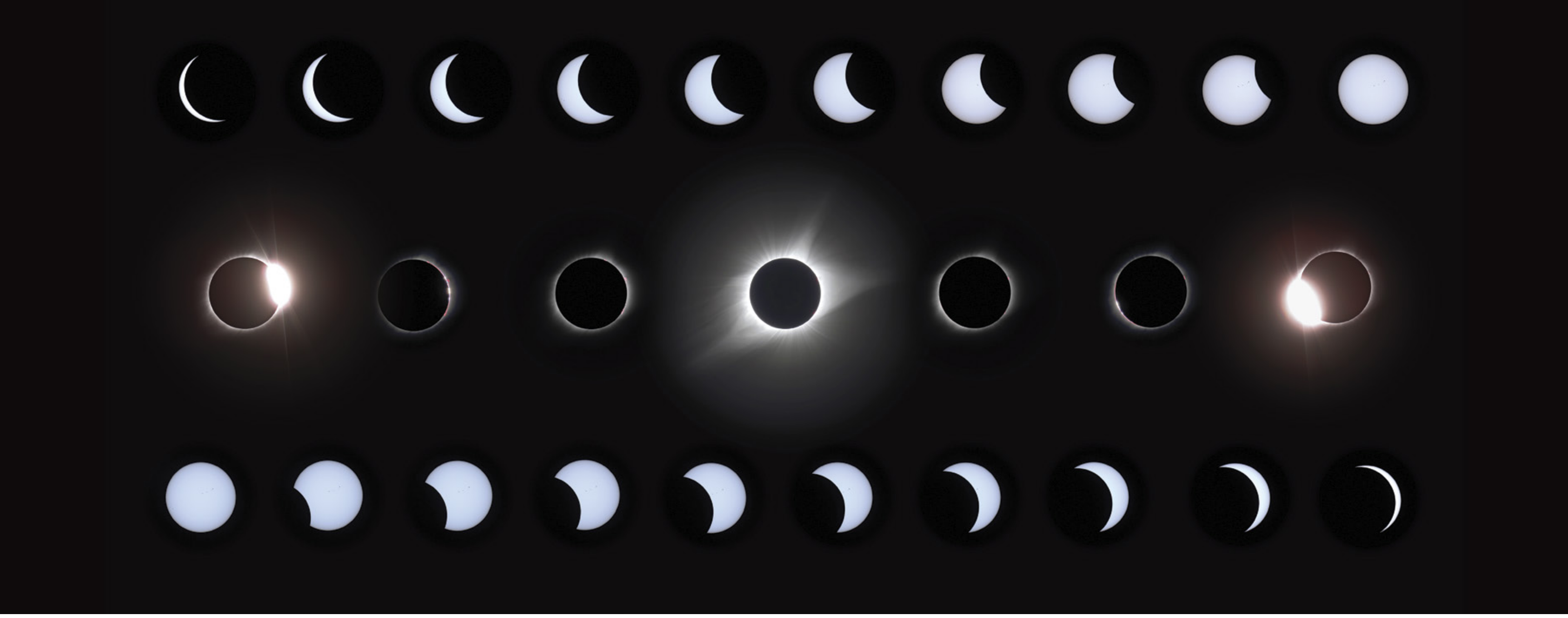

▲ The author captured this series of the 2017 total solar eclipse from Madras, Oregon.

RICK FIENBERG / TRAVELQUEST INTERNATIONAL

Say What You Mean

Don't be an inadvertent source of eclipse misinformation.

WITH SOLAR ECLIPSES coming to the Americas both this month and next April, many *S&T* readers will soon stand in the Moon's shadow. Many will stand in the media spotlight, too, as reporters and the public clamor for information on these events.

After the 2017 total solar eclipse, NASA sponsored a survey of the public's response (see **https://is.gd/2017NASA**). Among the results: "Nearly 20 million American adults traveled to a place other than their home city to improve their view of the eclipse . . ." But when asked to rate how enjoyable the experience was, these eclipse-chasers (most of them first-timers) gave it an average rating of 8.1 out of 10.

Anyone who has experienced totality under clear skies knows that on a scale of 1 to 10, it scores 11. Skies were mostly cloud-free on eclipse day in 2017, so what caused the somewhat tepid response? It turns out that two-thirds of those who traveled for the eclipse drove *closer* to the path of the Moon's shadow but not *into it*, the survey noted, "to increase the level of totality observed."

Oops. There's only *one* level of totality: 100%. Anything less is a partial eclipse, in which it doesn't get particularly dark or cold, you can't observe the Sun's corona or prominences, and you don't see stars or planets in the daytime. Somehow that message didn't get through to everyone. Perhaps it was all the pre-eclipse press claiming you see "more totality" the closer you get to the path's center but failing to clarify that this refers to the *duration* of totality, not the degree of obscuration. Those who thought they'd get some "level of totality" outside the path likely rated the eclipse as below their expectations.

With the approach of this month's annular eclipse (see pages 34 and 60) and next year's total eclipse (*S&T:* Apr. 2023, p. 26), misinformation is again appearing in the media. Some examples:

- "An annular or total solar eclipse is a rare event." Not really. There's one somewhere on Earth every year or two. Better to say: "It's rare for an annular or total solar eclipse to occur in your hometown or only a short drive away."
- "A total solar eclipse is a once-in-a-lifetime experience." Not for those who've experienced totality multiple times! Here's a better way to put it: "You should experience a total solar eclipse at least once in your lifetime."
- "A total solar eclipse is important scientifically." Sure, for a few researchers. But here's how you might pitch it to everyone else: "A total solar eclipse is the most beautiful and genuinely awesome celestial phenomenon you'll ever experience."
- "Never look at the Sun without eye protection." Good advice, though with one crucial exception for those within the path of a total (but not annular) eclipse. So say this instead: "*Except during totality*, don't look at the Sun without eye protection."

You don't want to be the person blamed when people keep their solar filters on during totality and miss the best part of the show. So be sure to say what you mean when sharing your expertise with family, friends, reporters, and anyone else who asks you about the coming solar eclipses.

■ Senior Contributing Editor **RICK FIENBERG** is Project Manager of the AAS's Solar Eclipse Task Force — see **eclipse.aas.org**. (The AAS publishes *S&T*.)


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